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STUDY OF POTENTIAL FOR MOTOR VEHICLE FUEL ECONOMY IMPROVEMENT

TECHNOLOGY PANEL REPORT NO. 4

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16. Abstract

This Technology Panel Report is report Number Four (4) of seven (7) panel reports prepared by special panels of a task force established under joint chairmanship of the U.S. Dept. of Transportation and the U.S. Environmental Protection Agency to conduct a study of the practicability of a 20% fuel economy improvement for new motor vehicles in the 1980 time frame. Materials developed by the various study panels were used in preparing the Report to Congress entitled "Potential for Motor Vehicle Fuel Economy Improvement" dated 24 October 1974 (second printing 18 November 1974).

The authors evaluate individual technologies which could produce improved automobile fuel economy in the areas of vehicle improvement (reduced weight and aerodynamic drag), transmission improvement, engine improvements and reduced performance acceleration. Potential 1980 fuel savings are estimated for each of these technologies. The more promising of these technologies are then combined in several different configurations to produce estimates of potential automobile fuel savings possible by 1980.

The authors conclude that the domestic automobile manufacturers could increase their sales weighted automobile fuel economy by more than 30% by 1980. The manufacturers of foreign imports which are more fuel efficient than domestic automobiles could meet a 20% improvement but could not meet a 30% improvement goal by 1980.

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PREFACE

This Technology Panel Report is number four (4) of a group of seven (7) prepared by special panels of the Task Force established under the joint chairmanship of DOT and EPA to conduct a study of the practicability of a fuel economy improvement standard of 20% for new motor vehicles produced in the 1980 time frame. Each panel addressed a major impact area and drew on a variety of sources in preparing its report, including previous DOT and EPA research, and industry and public comments.

Materials developed by the various study panels were used in preparing the Report to Congress entitled "Potential for Motor Vehicle Fuel Economy Improvement", dated 24 October 1974 (second printing, 18 November 1974). Assumptions and conclusions expressed in the panel reports, however, are those of the respective panels and do not necessarily reflect official positions or policies of the U.S. Department of Transportation, the U.S. Environmental Protection Agency, or the study Task Force.

The complete Panel Reports set consists of the following:

Report No. 1: Policy Assessment Panel Report
Report No. 2: Safety Implications Panel Report
Report No. 3: Air Quality and Emissions Panel Report
Report No. 4: Technology Panel Report
Report No. 5: Economics Panel Report
Report No. 6: Fuel Economy Test Procedures Panel Report
Report No. 7: Truck and Bus Panel Report

TABLE OF CONTENTS

Section Page

1. INTRODUCTION 1-1

2. SUMMARY, CONCLUSIONS AND BACKGROUND 2-1

2.1 Feasibility of Achieving a 20% Improvement in Sales-Weighted Fuel Economy By 1980 2-1

2.1.1 Emissions Impact 2-2
2.1.2 Safety Impact 2-2
2.1.3 Impact on Vehicle Characteristics 2-3
2.1.4 Production Capability 2-3
2.1.5 Impact on Natural Resources 2-4

2.2 Feasibility of Alternative Improvements and Timeframes 2-4

2.3 Automotive Fuel Economy Background 2-5

2.3.1 Fuel Economy Trends 2-5

3. APPROACH 3-1

3.1 Description of the Methodology 3-1

3.2 Assumptions and Constraints 3-1

3.2.1 Assumptions 3-1
3.2.2 Constraints 3-2

3.3 Description of Vehicle Size Classes 3-3

3.3.1 Passenger Cars 3-3
3.3.2 Light Duty Trucks 3-11

4. EVALUATION OF INDIVIDUAL TECHNOLOGIES 4-1

4.1 Vehicle Improvements 4-1

4.1.1 Vehicle Weight Reduction 4-6
4.1.2 Aerodynamic Drag 4-23
4.1.3 Rolling Resistance Reduction 4-25
4.1.4 Accessory Power Reduction 4-27

4.2 Transmission Improvements 4-29

4.2.1 Improved Automatic Transmission 4-29
4.2.2 Manual Transmissions 4-34
4.2.3 Continuously Variable Transmissions 4-36

TABLE OF CONTENTS (CONT.)

Section Page

4.3 Engine Improvements.............................. 4-39

4.3.1 Discussion.............................. 4-39
4.3.2 Conventional Gasoline Engines.......... 4-46
4.3.3 Stratified Charge Engines.............. 4-66
4.3.4 Diesel Engine.......................... 4-70

4.4 Acceleration Performance Reduction............ 4-78

5. SYNTHESIZED PASSENGER CARS.......................... 5-1

5.1 Selection of Improvements for 1980............ 5-1

5.1.1 Vehicle Improvements................... 5-1
5.1.2 Transmission Improvements.............. 5-3
5.1.3 Engine Improvements.................... 5-4

5.2 Selection of Improvements for 1985............ 5-5

5.2.1 Vehicle Improvements................... 5-5
5.2.2 Transmission Improvements.............. 5-6
5.2.3 Engine Improvements.................... 5-6

5.3 Combining Improvements........................ 5-7

5.4 Summary of Composite Improvements for 1980.... 5-9

6. INDIVIDUAL MANUFACTURERS REVIEWS.................. 6-1

6.1 General Motors (GM)........................... 6-1

6.1.1 Power Requirement Reduction............ 6-1
6.1.2 Driveline Improvements................. 6-2
6.1.3 Engine Improvements.................... 6-2
6.1.4 Composite Improvements................. 6-2

6.2 Ford.. 6-2

6.2.1 Power Requirement Reduction............ 6-4
6.2.2 Driveline Improvements................. 6-4
6.2.3 Engine Improvements.................... 6-4
6.2.4 Composite Improvements................. 6-4

6.3 Chrysler...................................... 6-6

6.3.1 Power Requirement Reduction............ 6-6
6.3.2 Driveline Improvements................. 6-6
6.3.3 Engine Improvements.................... 6-6
6.3.4 Composite Improvements................. 6-8

TABLE OF CONTENTS (CONT.)

Section Page

6.4 American Motors (AMC)........................ 6-8

6.4.1 Power Requirement Reduction............ 6-8
6.4.2 Driveline Improvements................. 6-8
6.4.3 Engine Improvements.................... 6-9
6.4.4 Composite Improvements................. 6-10

6.5 Volkswagen (VW).............................. 6-10

6.5.1 Power Requirement Reduction............ 6-10
6.5.2 Driveline Improvements................. 6-10
6.5.3 Engine Improvements.................... 6-10
6.5.4 Composite Improvements................. 6-10

6.6 Toyota....................................... 6-12

6.6.1 Power Requirement Reduction............ 6-12
6.6.2 Driveline Improvements................. 6-12
6.6.3 Engine Improvements.................... 6-12
6.6.4 Composite Improvements................. 6-12

6.7 Nissan....................................... 6-12

6.7.1 Power Requirement Reduction............ 6-14
6.7.2 Driveline Improvements................. 6-14
6.7.3 Engine Improvements.................... 6-14
6.7.4 Composite Improvements................. 6-14

6.8 Volvo.. 6-14

6.8.1 Power Requirement Reduction............ 6-16
6.8.2 Driveline Improvements................. 6-16
6.8.3 Engine Improvements.................... 6-16
6.8.4 Composite Improvements................. 6-16

6.9 Fiat... 6-16

6.9.1 Power Requirement Reduction............ 6-16
6.9.2 Driveline Improvements................. 6-16
6.9.3 Engine Improvements.................... 6-16
6.9.4 Composite Improvements................. 6-19

6.10 Honda....................................... 6-19

6.10.1 Power Requirement Reduction........... 6-19
6.10.2 Driveline Improvements................ 6-19
6.10.3 Engine Improvements................... 6-19
6.10.4 Composite Improvements................ 6-19

TABLE OF CONTENTS (CONT.)

Section Page

6.11 Toyo Kogyo (T-K).. 6-21

6.11.1 Power Requirement Reduction............ 6-21
6.11.2 Driveline Improvements................. 6-21
6.11.3 Engine Improvements.................... 6-21
6.11.4 Composite Improvements................. 6-21

6.12 Audi... 6-21

6.12.1 Power Requirement Reduction............ 6-23
6.12.2 Driveline Improvements................. 6-23
6.12.3 Engine Improvements.................... 6-23
6.12.4 Composite Improvements................. 6-23

7. IMPROVEMENTS IN FUEL ECONOMY FOR LIGHT DUTY TRUCKS (LDT).. 7-1

7.1 Light Duty Truck Classes........................ 7-2

REFERENCES.. R-1

LIST OF ILLUSTRATIONS

Figure		Page
2-1	Fleet Average Fuel Economy Versus Calendar Year....	2-7
2-2	New Model Automobile Fuel Economy Versus Model Year..	2-7
2-3	Passenger Car Sales by Market Class (Including Imports)..	2-9
4-1	Performance Map - Typical Gasoline Engine..........	4-4
4-2	Effect of Weight Reduction on Fuel Economy.........	4-7
4-3	Synthesized Versus Typical Vehicle.................	4-13
4-4	NO_x Emissions Versus Weight (Uncontrolled Cars)....	4-16
4-5	NO_x Emissions Versus Weight (1973 Cars)............	4-16
4-6	Percentage Fatal/Serious Injury versus Vehicle Weight...	4-18
4-7	Crush Distance versus Vehicle Weight...............	4-19
4-8	Fuel Economy versus Vehicle Weight.................	4-44
4-9	Percent Change in Fuel Economy Between Uncontrolled and 1974 Models versus Inertia Weight..............	4-44
4-10	Fuel Economy versus Weight for "Optimized Vehicles" Compared to 1974 Average.................	4-45
4-11	Oxidation Catalyst and EGR System (Typical 1975 System)...	4-50
4-12	Advanced QHI System (Super EFE)....................	4-55
4-13	Start Catalyst System.............................	4-57
4-14	Cold Storage System...............................	4-60
4-15	HC Emission Rate with and without Cold Storage.....	4-61
4-16	Advanced Lean Burn System versus 1974 Average and Best 1975 Data......................................	4-64

LIST OF TABLES

Table Page

2-1 POTENTIAL AVERAGE TECHNOLOGICAL IMPROVEMENT IN AUTOMOTIVE FUEL ECONOMY BY MANUFACTURER............. 2-1

2-2 PERCENT OF SALES BY MARKET CLASS - DOMESTICS........ 2-8

2-3 PERCENT OF U.S. SALES BY MARKET CLASS............... 2-8

2-4 PERCENT OF SALES BY MANUFACTURER AND MARKET CLASS... 2-10

2-5 AUTO IMPORT SALES 1973-4............................ 2-11

2-6 FULL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1970)............... 2-13

2-7 FUEL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1973)............... 2-14

2-8 FUEL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1974)............... 2-15

3-1 1973 MODEL YEAR SALES AND TYPICAL SPECIFICATIONS.... 3-3

3-2 VEHICLE CLASSIFICATIONS............................. 3-4

4-1 ENERGY LOSSES - EPA URBAN AND HIGHWAY DRIVING....... 4-2

4-2 EPA URBAN AND HIGHWAY DRIVING STATISTICS............ 4-2

4-3 EFFECT ON 0-60 MPH ACCELERATION PERFORMANCE OF REDUCTIONS IN WEIGHT, DRAG AND ROLLING RESISTANCE... 4-5

4-4 ESTIMATED IMPROVEMENT IN ECONOMY (4000 lb. Car) WITH 10% WEIGHT REDUCTION............................ 4-7

4-5 FUEL ECONOMY SENSITIVITY TO WEIGHTs................. 4-8

4-6 MATERIALS SUBSTITUTION POTENTIAL SAVINGS............ 4-9

4-7 WEIGHT EFFICIENT VEHICLES........................... 4-12

4-8 INERTIA WEIGHT COMPARISON OF VEHICLE TYPES.......... 4-12

4-9 AUTOMATIC TRANSMISSION LEAD TIME.................... 4-31

4-10 CVT COST INCREMENTS AND INVESTMENT.................. 4-38

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LIST OF TABLES (CONTINUED)

Table		Page
4-11	1974 ECONOMY VERSUS OPTIMUM ECONOMY................	4-47
4-12	POSSIBLE ECONOMY IMPROVEMENTS WITH ENGINE OPTIMIZATION....................................	4-47
4-13	CATALYST PERFORMANCE CRITERIA......................	4-56
4-14	PERCENT CHANGE IN FUEL ECONOMY FOR PRECHAMBER STRATIFIED CHARGE ENGINES...........................	4-67
4-15	TYPICAL WEIGHT TO CID RATIOS.......................	4-79
4-16	SENSITIVITIES OF TYPICAL VEHICLES TO REDUCTION IN ENGINE SIZE......................................	4-79
5-1	EFFECT OF COMBINING INDIVIDUAL IMPROVEMENTS........	5-8
5-2	EFFECT OF COMBINING IMPROVEMENTS..................	5-9
5-3	SUMMARY OF SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT (1980 VEHICLES).........................	5-10
5-4	SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT 1980 VEHICLE - LARGE SIZE..........................	5-11
5-5	SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT 1980 VEHICLE - MID-SIZE............................	5-12
5-6	SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT 1980 VEHICLE - SMALL SIZE..........................	5-13
5-7	1980 LARGE SIZE VEHICLE: ENGINE TECHNOLOGY........	5-14
5-8	1980 LARGE SIZE VEHICLE: "OTHER" VEHICLE TECHNOLOGY..	5-16
6-1	SUMMARY CHART: GM.................................	6-3
6-2	SUMMARY CHART: FORD...............................	6-5
6-3	SUMMARY CHART: CHRYSLER...........................	6-7
6-4	SUMMARY CHART: AMC................................	6-9
6-5	SUMMARY CHART: VW.................................	6-11
6-6	SUMMARY CHART: TOYOTA.............................	6-13
6-7	SUMMARY CHART: NISSAN.............................	6-15

LIST OF TABLES (CONTINUED)

Table		Page
6-8	SUMMARY CHART: VOLVO	6-17
6-9	SUMMARY CHART: FIAT	6-18
6-10	SUMMARY CHART: HONDA	6-20
6-11	SUMMARY CHART: TOYO KOGYO	6-22
6-12	SUMMARY CHART: AUDI	6-24
6-13	SUMMARY TABLE - INDIVIDUAL MANUFACTURERS	6-25
7-1	U.S. NEW TRUCK REGISTRATIONS BY GVW CLASS	7-2
7-2	U.S. TRUCK PRODUCTION BY MAKE AND ENGINE TYPE	7-3
7-3	U.S. NEW TRUCK REGISTRATIONS BY GVW CLASS	7-3
7-4	LIGHT DUTY TRUCK STATISTICS	7-4
7-5	IMPORTED 1/2-TON PICK-UP TRUCK DATA	7-5

1. INTRODUCTION

This Technology Panel report of the joint U.S. Environmental Protection Agency (EPA) - U.S. Department of Transportation (DOT) 120 day fuel economy study is one of seven panel reports submitted to the Study Task Force: Eric Stork, EPA; R.E. Goodson, DOT; and representatives of the Treasury Department, the Federal Energy Administration, and the Council of Environmental Quality.

The technology panel which produced this report was comprised of the following members: Richard L. Strombotne (Co-Chairman), Robert Husted, Herbert Gould and Samuel Powel from DOT, Karl Hellman (Co-Chairman) and Thomas Austin from EPA. Supporting the panel in an advisory capacity were Mayo Stuntz from the Federal Energy Administration, and R.R. John and A.C. Malliaris from the Transportation Systems Center, DOT.

This report contains information about the technical approaches, cost, lead time and the investment considered practicable in order to meet a requirement of a 20 percent improvement in sales-weighted fuel economy over 1974 as a base for each automobile manufacturer in the model 1980.

2. SUMMARY, CONCLUSIONS AND BACKGROUND

2.1 FEASIBILITY OF ACHIEVING A 20% IMPROVEMENT IN SALES-WEIGHTED FUEL ECONOMY BY 1980

The technology is available to satisfy the requirement to improve sales-weighted fuel economy by 20% over the 1974 baseline by 1980. However, at least one manufacturer will not be able to achieve the standard. This manufacturer currently has the best economy of all makers in the U.S. market. The task of improving by 20% is relatively easy for manufacturers with relatively low fuel economy in 1974 but more difficult for those who are already demonstrating good economy. Greater than 30% potential for improved fuel economy by 1980 is estimated for the domestic manufacturers, independent of sales mix considerations. Table 2-1 summarizes the estimated improvements potential for the greater part of the automotive manufacturers with sales in the United States.

TABLE 2-1 POTENTIAL AVERAGE TECHNOLOGICAL IMPROVEMENT IN AUTOMOBILE FUEL ECONOMY BY MANUFACTURER

Manufacturer	1974 Fuel Economy(mpg)	1980 Potential Fuel Economy(mpg)	Percent Potential Improvement
GM*	12.2	17.4	+43
Ford*	14.4	19.5	+35
Chrysler*	14.0	18.7	+33
AMC*	16.6	23.4	+41
VW	25.8	31.3	+21
Toyota	22.2	29.5	+33
Nissan	24.1	29.3	+22
Volvo	19.3	24.5	+27
Fiat	22.0	30.0	+36
Toyo Kogyo	13.6	26.0	+91
Honda	30.3	32.2	+6
Audi	22.3	27.7	+24

*Not including engine resizing or accessory improvements.

There are two basic approaches open to manufacturers for improving their sales-weighted fuel economy. The first approach is to improve the fuel economy of the individual vehicle types which they produce. The second approach is to alter the mix of vehicle types offered for sale, shifting production toward vehicles which have better fuel economy. These approaches, obviously, are not mutually exclusive, however, the second approach assumes that there will be a market for the altered production mix. In the first approach, the fuel economy may generally be improved by more than 20% by improving vehicle propulsion systems. In particular, two improvements are most beneficial - improved transmissions and modified engine emission control systems that permit use of best engine settings for fuel economy. In addition, reduced vehicle weight and aerodynamic drag provide further improvements in fuel economy.

2.1.1 Emissions Impact

Most techniques available for improving the fuel economy of individual vehicle types have a beneficial effect on the capability to meet future emission standards. For conventional and stratified charge engines, however, fuel economy optimization tends to increase the difficulty in achieving stringent hydrocarbon standards. The hydrocarbon problem is considered to be readily solvable at the 2.0 grams per mile (g/mi) NO_x level but expanded development programs will be required to achieve .41 g/mi HC in combination with .4 g/mi NO_x while maintaining engine adjustments that are optimum for fuel economy. Firm conclusions about the fuel economy performance of systems targeted toward .4 g/mi NO_x are difficult, due to the current lack of effort in this area.

2.1.2 Safety Impact

Achievement of fuel economy improvements need not have a negative impact on the safety characteristics of individual vehicles.

2.1.3 Impact on Vehicle Characteristics

Fuel economy improvement is achievable without adversely impacting the ability of vehicles to carry passengers and their luggage. Performance, driveability, ride and handling can be maintained or improved. The use of aluminum body panels however probably will be and maintainability is expected to be comparable to current vehicles.

2.1.4 Production Capability

For most car lines sufficient lead time remains between the spring of 1975 and the 1980 model year for the design, development and tooling of all new bodies more consistent with the goal of improved fuel economy. It appears that decisions to build such bodies may have already been made by some manufacturers and, therefore, lighter weight bodies will appear before 1980.

Replacement of many body parts currently fabricated from sheet steel with aluminum appears to be feasible and worthwhile on a total energy basis (accounting for the higher energy requirements of aluminum processing). The higher cost of aluminum per pound could be completely offset by the reduced material requirements on a weight basis. The technology panel did not, however, rely heavily on the use of aluminum body panel replacement in light of concerns over the continued availability of aluminum at costs that would keep it competitive with steel in the auto industry. The use of aluminum body panels, however, probably will be an option open to manufacturers who want to continue marketing large, luxury vehicles.

Sufficient lead time remains for the modifications to the conventional engine considered by the technology panel to be included on 100% of production in model year 1980 (See Section 4.3.2). Carbureted pre-chamber stratified charge engines could also have a major impact by 1980. Open chamber stratified charge and Diesel engines could only have limited impact due to the considerable lead time required for engine development and the design, development and tooling of high pressure, direct cylinder, fuel injection systems.

Both positive and negative first-cost effects will be realized if a fuel economy improvement standard is established. More sophisticated engine systems could be expected to increase costs by approximately $100 over what would be required to meet emission standards with no regard for improved fuel economy. Transmission improvements are estimated at less than $25. Reduced vehicle weights, however, can be expected to more than offset both of these effects. The sticker price of the standard size car could probably be reduced by $250-$500 assuming equal manufacturer profit/car, while the mid-size cars would have lesses savings and small cars may incur a slight cost penalty.

The operating cost of each vehicle over its lifetime would be reduced by $640 based on a 20% economy increase over a baseline of 15.5 mpg with $0.60/gallon fuel prices.

2.1.5 Impact on Natural Resources

The impact of any fuel economy improvement on natural resources has obvious benefits from the petroleum consumption standpoint. If materials substitutions do not reduce weight sufficiently, reducing raw materials usage (particularly ferrous metals) should be a popular approach toward achieving the standard. The extended use of radial tires will also beneficially impact natural resource requirements as tire life can be expected to increase by a factor of two.

2.2 FEASIBILITY OF ALTERNATIVE IMPROVEMENTS AND TIMEFRAMES

Attempts to predict the capability of the industry to achieve any fuel economy improvement standard that comes into effect prior to 1980 are frustrated by the fact that current industry plans, which have already been made and will come into effect prior to 1980, were not made available to the technology panel. While we expect that the capability to reduce average vehicle weights will be achieved prior to 1980, the technology panel has based its projection on the engine improvements considered achievable regardless of current manufacturing plans.

Based on an analysis of the variety of emission control systems that will be used for 1975 it appears likely that many manufacturers fuel economy can be improved by 10-15% if all manufacturers utilize the most efficient emission control systems. This benefit can be realized by 1978. It is important to note, however, that not all manufacturers will be able to achieve this kind of improvement because some manufacturers already are demonstrating fuel economy superior to the competition. If each manufacturer is forced to improve his sales weighted fuel economy by 10-15% in 1978, the manufacturers who market the vehicles which are currently the most efficient would be under severe market pressure.

For 1980 and beyond a manufacturer's current plans are less important as sufficient lead time remains for changes in plans to be made. "Basic market demand' could be satisfied with improvements of up to 30%, but even requiring the 20% improvement might lead to the elimination of some foreign manufacturers. Many foreign manufacturers currently market the type of vehicle that other manufacturers would essentially copy to achieve a substantial improvement in economy. Manufacturers who currently sell the most efficient vehicles would have a more difficult job to make further improvements in full economy than manufacturers of cars with poor economy. An average fleet fuel economy of 16.8 mpg amounts to a 20% overall improvement over 1974 levels.

Beyond 1980 greater than 50% improvements are possible through the application of further weight reductions and conversion to Diesel engines.

2.3 AUTOMOTIVE FUEL ECONOMY BACKGROUND

2.3.1 Fuel Economy Trends

2.3.1.1 Fleet Average Fuel Economy Trends - As used here fleet average fuel economy means the average fuel economy of all vehicles on the road at a given point in time. For example in 1970, at the end of the year, the fleet would be composed of varying numbers of 1971, 1970, 1969, 1968 and earlier model year vehicles.

There is general concensus that the fleet average fuel economy has declined over the last several years. The fleet average fuel economy reported by the U.S. Department of Transportation (DOT) is shown in Figure 2-1. This estimate is based on the total miles of automobile travel reported by each state (from traffic surveys) and the total gallons of gasoline sold to automobiles from fuel tax data. Corrections are made for many factors such as the percent of taxed gasoline sold to people who used the gasoline in lawnmowers, boats and other non-auto engines.

2.3.1.2 New Model Fuel Economy Trends - Another important measure of fuel economy trends is new model fuel economy. This is defined as the average fuel economy of vehicles of a given model year. For 1970, for example, the new model fuel economy would be the average fuel economy of all 1970 model year vehicles.

This measure of fuel economy has also declined over the years, as shown in Figure 2-2 which was derived from an analysis of EPA surveillance data.

2.3.1.3 Factors Influencing the Trends - The major vehicle-related factors that have influenced the above discussed trends are the relative portions of automobiles of different types sold, which are referred to as model mix trends; and trends in the fuel economy of the different types of automobiles themselves.

a. Model Mix Trends - The different types of vehicle classes in which trend data exist are the ones used by the industry, namely, subcompact, compact, intermediate, standard and speciality. These classes are discussed in more detail later. Over the last several years the fraction of the total market accounted for by the classes has changed. This trend is shown in Figure 2-3.

As can be seen, the percent of the market in each class has tended to change over the years, compared to the earliest years. For example in 1953 the market was virtually all standards, while more recently the market share for the standards has dropped.

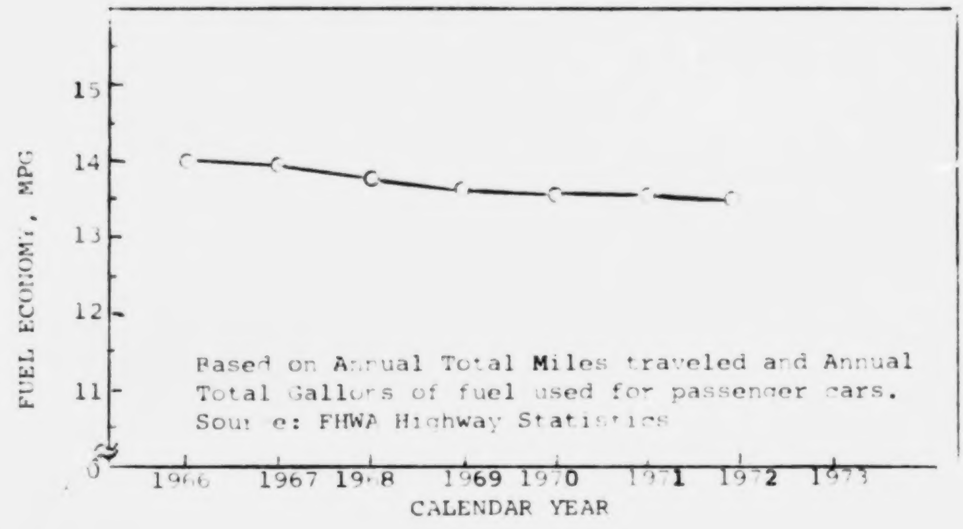


Figure 2-1 Fleet Average Fuel Economy Versus Calendar Year

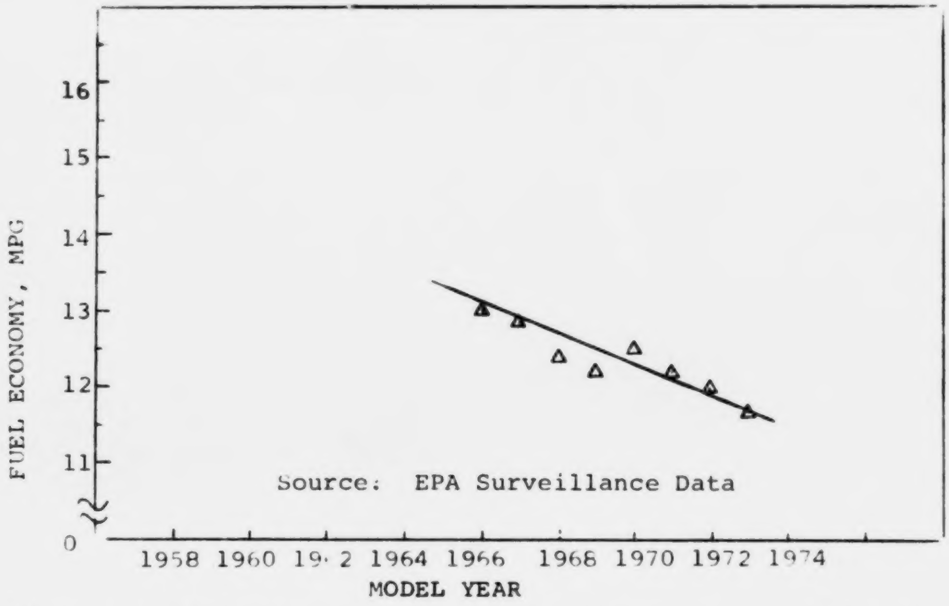


Figure 2-2 New Model Automobile Fuel Economy Versus Model Year

For 1974 the market has undergone substantial changes with major fluctuations occuring during the model year itself. For example, Automotive News reported that in April 1974 compared to April 1973, the following shifts had occurred for the domestic manufacturers (Table 2-2, 2-3).

TABLE 2-2 PERCENT OF SALES BY MARKET CLASS - DOMESTICS

	Sub-Compact	Compact	Inter-mediate	Std.	Spec.
April '73	12.06	18.09	22.99	35.43	11.43
April '74	10.96	22.21	23.39	27.21	16.23

As an indication of the changing market during 1974, the following figures were reported for the domestic subcompact class:

April 1973	January 1974	April 1974
12.06%	15.0%	10.96%

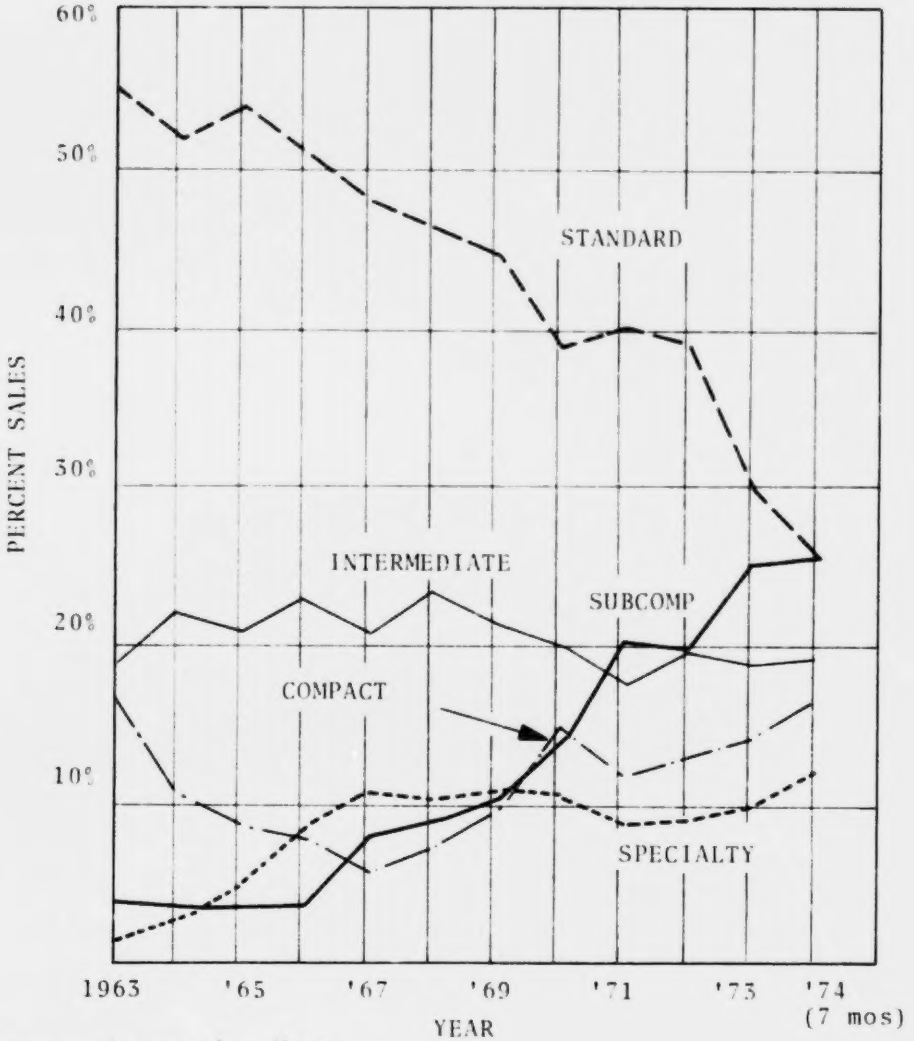
Because of the fluctuating nature of the 1974 market, the actual model mix to be sold is not precisely known. At the time of the preparation of this report many 1974 models remained to be sold. Data for 1970, 1973 and the seven months of the 1974 model year are listed below, for the U.S. Market as a whole, including imports.

TABLE 2-3 PERCENT OF U.S. SALES BY MARKET CLASS*

	Sub-Compact	Compact	Inter-mediate	Std.	Spec.
1970	13.8	14.6	21.7	39.9	11.1
1973	21.6	14.8	20.4	31.8	11.4
1974**	25.1	17.4	17.2	27.8	12.5

**first seven months

*Source: Automotive News



Source: Automotive News

Figure 2-3 Passenger Car Sales by Market Class (Including Imports)

Including the imported vehicles increases the market share of the subcompacts, since most imported vehicles are in that class.

For the four major domestic manufacturers, Table 2-4 gives the percent of each manufacturer's total sales in the market classes for the years 1970, 1973, and the first seven months of 1974.

The specialty class is not shown because the vehicles in that class belong to no special type. The lack of data for Chrysler in the sub-compact class is misleading because Chrysler sells an imported vehicle, the Colt, but it is not included with Chrysler in the data available.

TABLE 2-4 PERCENT OF SALES BY MANUFACTURER AND MARKET CLASS*

Manufacturer	GM	Ford	Chrysler	AMC
Market Class - Subcompact				
1974	10.9	18.5	---	31.7
1973	8.8	18.1	---	35.3
1970	0.7	3.3	---	16.1
Market Class - Compact				
1974	11.6	14.0	46.1	36.6
1973	10.1	13.5	39.7	35.3
1970	7.1	17.6	32.2	32.2
Market Class - Intermediate				
1974	20.8	19.8	22.3	17.1
1973	24.9	21.5	22.9	14.7
1970	29.5	19.9	18.9	38.7

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*Source: Automotive News; Ward's Automotive Yearbook

TABLE 2-4 PERCENT OF SALES BY MANUFACTURER AND MARKET CLASS - CONTINUED

Manufacturer	GM	Ford	Chrysler	AMC
Market Class - Standard				
1974	39.7	28.4	29.2	7.3
1973	41.6	33.8	34.4	8.8
1970	49.1	45.6	39.0	---

During the first seven month period of 1974, the specialty class accounted for 17.0, 19.3, 2.3 and 7.3 percent of GM, Ford, Chrysler and AMC sales respectively. In addition, Chrysler, Ford and GM import the Colt, Capri and Opel subcompact models respectively. Sales for 1973 and 1974 (5 months) for these were as follows:

TABLE 2-5 AUTO IMPORT SALES 1973-4

	Colt	Capri	Opel
1974 (5 months)	15,723	30,294	24,037
1973	38,000	115,153	69,748

Other imports included:

	1974 (5 months)	1973
VW	147,778	480,602
Toyota	106,157	278,111
Nissan (Datsun)	76,091	231,129
Fiat	25,357	58,669
Honda	19,627	46,000
Audi	20,605	46,800
Mazda	33,858	104,328
Volvo	19,554	61,042

Tables 2-6 through 2-8 give a detailed breakdown of vehicle mix and fuel economies for the years 1970, 1973, and 1974. The fuel economy values are from the E.P.A. Certification Tests which simulate an urban driving schedule which includes a cold start. The tables provide information about average vehicle inertia test weight, engine displacement (C.I.D.), weight per unit engine displacement (nominally equivalent to the acceleration time from 0 to 60 mph) and the average rear axle ratio.

b. Vehicle Trends - The second type of factors that influence the trend in fuel economy is the changes that have been made to individual vehicles, apart from the market as a whole. These changes can be grouped into three classes; changes to the engine, vehicle weight changes and accessory use trends.

The engine trends have generally been two-fold; changes in engine displacement and compression, and changes in engine calibration.

In general, displacement has been increased, compression ratio has been decreased and engine calibration (especially spark timing) has been changed from the optimum. All of these trends are in the direction of reduced fuel economy.

Other engine-related trends have been in the direction of improved fuel economy, such as engine air/fuel ratio and air/fuel ratio control, but the resulting overall effect has been to reduce fuel economy on the average. The reduction in fuel economy has been the greatest for the heavier vehicles. Weight classes 3500 lbs and below currently have essentially the same fuel economy as did uncontrolled cars. Heavier vehicles have suffered losses of 15-20%.

TABLE 2-6 FUEL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1970)

MKT CLASS / MFR	1970	STANDARD	INTERMED	COMPACT	SUBCOMPACT	SPECIALTY	ALL
GM	% SALES	20.0%	12.0%	2.9%	0.3%	5.5%	40.7%
	FUEL ECON	10.9	13.1	13.7	--	11.7	11.6
	INERTIA WT	4720	4041	3500	2500	4005	4320
	C.I.D.	389	334	264	140	358	358
	WT/C.I.D.	12.2	12.1	13.3	17.9	11.2	12.2
	AXLE RATIO	3.07	3.10	3.09	2.53	3.52	3.12
FORD	% SALES	12.5%	5.4%	4.8%	0.9%	3.6%	27.2%
	FUEL ECON	11.1	11.7	19.2	--	11.5	12.2
	INERTIA WT	4526	4000	2814	2250	3938	3967
	C.I.D.	359	293	177	110	323	323
	WT/C.I.D.	12.6	13.7	15.9	20.5	12.2	13.7
	AXLE RATIO	3.13	2.81	2.84	3.55	2.98	3.01
CHRYSLER	% SALES	6.4%	3.1%	5.3%		1.6%	16.4%
	FUEL ECON	12.3	13.3	15.3		12.0	13.3
	INERTIA WT	4587	3755	3500		3850	4007
	C.I.D.	346	302	244		321	302
	WT/ C.I.D.	13.3	12.4	14.3		12.0	13.3
	AXLE RATIO	3.08	3.07	3.22		3.23	3.14
AMC	% SALES		1.2%	1.0%	0.5%	0.4%	3.1%
	FUEL ECON		13.1	16.5	17.9	15.2	15.0
	INERTIA WT		3913	3000	3000	3500	3419
	C.I.D.		284	207	199	298	247
	WT/C.I.D.		13.8	14.5	15.1	11.7	14.0
	AXLE RATIO		2.94	2.96	2.73	3.15	2.95
VW	% SALES				7.0%		7.0%
	FUEL ECON				21.4 *		21.4 *
	INERTIA WT				2379		2379
	C.I.D.				97		97
	WT/C.I.D.				24.5		24.5
	AXLE RATIO				4.13		4.13
TOYOTA	% SALES			0.1%	2.2%		2.3%
	FUEL ECON			14.7	23.0 *		23.0
	INERTIA WT			3500	2412		2459
	C.I.D.			138	100		102
	WT/C.I.D.			25.4	24.1		24.2
	AXLE RATIO			4.11	3.90		3.91
OTHER IMPORTS	% SALES			0.5%	2.9%		3.4%
	FUEL ECON			--	20.0 *		20.0 *
	INERTIA WT			3072	2343		2450
	C.I.D.			130	83		90
	WT/C.I.D.			23.6	28.2		27.6
	AXLE RATIO			4.11	4.01		4.03
TOTAL DOMESTIC	% SALES	38.9%	21.7%	14.0%	1.7%	11.1%	87.4%
	FUEL ECON	11.2	12.7	16.1	--	11.8	12.2
	INERTIA WT	4636	3979	3230	2500	3941	4116
	C.I.D.	372	317	222	140	339	326
	WT/C.I.D.	12.5	12.6	14.5	17.9	11.6	12.9
	AXLE RATIO	3.08	3.01	3.08	3.16	3.28	3.09
TOTAL IMPORTS	% SALES			0.6%	12.1%		12.7%
	FUEL ECON			--	21.3		21.3
	INERTIA WT			3128	2364		2400
	C.I.D.			131	94		96
	WT/C.I.D.			23.9	25.1		25.0
	AXLE RATIO			4.11	4.03		4.03
ALL	% SALES	38.9%	21.7%	14.6%	13.8%	11.1%	100%
	FUEL ECON	11.2	12.7	16.1	21.0	11.8	12.9
	INERTIA WT	4636	3979	3225	2381	3941	3902
	C.I.D.	372	317	218	100	339	297
	WT/C.I.D.	12.5	12.6	14.8	23.8	11.6	14.3
	AXLE RATIO	3.08	3.01	3.12	3.91	3.28	3.20

Source: Sales & specs from Automotive News

* Estimate

TABLE 2-7 FUEL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1973)

MFR \ CLASS	1973	STANDARD	INTERMED	COMPACT	SUBCOMPACT	SPECIALTY	ALL
GM	% SALES	19.0%	11.4%	4.6%	4.0%	6.7%	45.7%
	FUEL ECON	10.0	10.7	12.7	19.4	9.5	10.8
	INERTIA WT	4848	4357	3546	2500	4299	4308
	C.I.D.	391	350	315	140	392	351
	WT/C.I.D.	12.4	12.4	11.3	17.9	11.0	12.6
	AXLE RATIO	2.91	3.13	3.07	2.63	3.05	2.98
FORD	% SALES	8.0%	5.1%	3.2%	4.3%	3.1%	23.7%
	FUEL ECON	8.9	8.7	12.9	19.2	8.3	10.2
	INERTIA WT	4635	4000	3000	2750	4282	3889
	C.I.D.	396	336	271	119	388	315
	WT/C.I.D.	11.7	11.9	11.1	23.1	11.0	13.6
	AXLE RATIO	2.75	3.15	2.98	3.49	2.86	3.02
CHRYSLER	% SALES	4.5%	3.0%	5.2%		0.4%	13.1%
	FUEL ECON	10.0	9.9	16.2		10.0	11.8
	INERTIA WT	4671	4000	3376		3500	3968
	C.I.D.	375	323	246		360	311
	WT/C.I.D.	12.5	12.4	13.7		9.7	12.9
	AXLE RATIO	3.12	3.23	3.23		3.23	3.19
AMC	% SALES	0.3%	0.5%	1.2%	1.2%	0.2%	3.4%
	FUEL ECON	11.2	12.2	18.9	18.0	12.9	15.9
	INERTIA WT	4379	4214	3427	3259	3434	3568
	C.I.D.	332	306	251	251	304	269
	WT/C.I.D.	13.2	13.8	13.7	13.0	11.3	13.3
	AXLE RATIO	3.15	3.15	2.73	2.73	3.54	2.88
VW	% SALES				3.9%		3.9%
	FUEL ECON				22.0		22.0
	INERTIA WT				2316		2316
	C.I.D.				96		96
	WT/C.I.D.				24.1		24.1
	AXLE RATIO				3.83		3.83
TOYOTA	% SALES				2.0%	0.5%	2.5%
	FUEL ECON				20.4	19.0	20.1
	INERTIA WT				2398	2600	2438
	C.I.D.				106	120	109
	WT/C.I.D.				22.6	21.7	22.4
	AXLE RATIO				3.8	3.7	3.78
OTHER IMPORTS	% SALES		0.4%	0.6%	6.2%	0.5%	7.7%
	FUEL ECON		13.3	16.2	19.9	18.6	19.0
	INERTIA WT		4000	--	2470	2500	2558
	C.I.D.		168	--	100	143	107
	WT/C.I.D.		23.8		24.7	17.5	24.1
	AXLE RATIO		3.92	--	3.63	4.43	3.70
TOTAL DOMESTIC	% SALES	31.8%	20.0%	14.2%	9.5%	10.4%	85.9%
	FUEL ECON	9.7	10.0	14.3	19.1	9.2	10.9
	INERTIA WT	4925	4456	3389	2738	4090	4219
	C.I.D.	389	341	274	124	387	329
	WT/C.I.D.	12.7	13.1	12.4	22.1	10.6	13.5
	AXLE RATIO	2.90	3.15	3.08	3.02	3.01	3.01
TOTAL IMPORTS	% SALES		0.4%	0.6%	12.1%	1.0%	14.1%
	FUEL ECON		13.3	16.2	20.6	18.8	19.9
	INERTIA WT		4000	--	2415	2500	2468
	C.I.D.		168	--	99	130	103
	WT/C.I.D.		23.8	--	24.4	19.2	24.0
	AXLE RATIO		3.92	--	3.36	4.01	3.42
ALL	% SALES	31.8%	20.4%	14.8%	21.6%	11.4%	100.0%
	FUEL ECON	9.7	10.0	14.4	19.9	9.6	11.6
	INERTIA WT	4925	4447	3389	2557	3963	3979
	C.I.D.	389	337	274	110	366	298
	WT/C.I.D.	12.7	13.2	12.4	23.2	10.8	14.8
	AXLE RATIO	2.90	3.17	3.08	3.15	3.09	3.06

Source: Sales & specs from Automotive News, Wards Automotive

TABLE 2-8 FUEL ECONOMY (EPA Certification Data) AND OTHER IMPORTANT STATISTICS AS A FUNCTION OF AUTOMOBILE MARKET CLASS AND MANUFACTURER, (1974)

CLASS MFR	1974 *	STANDARD	INTERMED	COMPACT	SUBCOMPACT	SPECIALTY	ALL
GM	% SALES	16.8%	8.8%	4.9%	4.6%	7.2%	42.3%
	FUEL ECON	9.1	9.1	14.3	20.4	8.6	10.0
	INERTIA WT	4850	4307	3666	2782	4568	4327
	C.I.D.	405	332	303	140	387	346
	WT/C.I.D.	12.0	13.0	12.1	19.9	11.8	13.0
	AXLE RATIO	2.84	2.88	3.04	2.53	3.05	2.87
FORD	% SALES	6.9%	4.8%	3.4%	4.5%	4.7%	24.3%
	FUEL ECON	9.4	10.5	15.2	19.2	14.4	12.3
	INERTIA WT	5031	4500	3500	3000	3938	4124
	C.I.D.	401	329	258	122	276	291
	WT/C.I.D.	12.5	13.7	13.6	24.6	14.3	15.5
	AXLE RATIO	2.81	2.86	2.91	3.47	3.21	3.03
CHRYSLER	% SALES	3.8%	2.9%	6.0 %		0.3%	13.0%
	FUEL ECON	8.9	10.1	14.6			11.3
	INERTIA WT	4828	4000	3500		3753	4002
	C.I.D.	409	309	229		380	303
	WT/ C.I.D.	11.8	12.9	15.3		9.9	13.6
	AXLE RATIO	2.74	3.06	3.15		—	3.00
AMC	% SALES	0.3%	0.7%	1.5%	1.3%	0.3%	4.1%
	FUEL ECON	10.4	11.3	13.9	14.9	11.8	13.2
	INERTIA WT	4160	4022	3230	3039	3487	3394
	C.I.D.	332	298	250	250	304	268
	WT/C.I.D.	12.5	13.5	12.9	12.2	11.5	12.6
	AXLE RATIO	3.15	3.19	3.20	3.54	3.54	3.30
VW	% SALES				4.2%		4.2%
	FUEL ECON				21.6 **		21.6**
	INERTIA WT				2350 **		2350 **
	C.I.D.				96 **		96 **
	WT/C.I.D.				24.5**		24.5**
	AXLE RATIO				3.90 **		3.90**
TOYOTA	% SALES				2.6%		2.6%
	FUEL ECON				19.8 **		19.8**
	INERTIA WT				2375 **		2375 **
	C.I.D.				106 **		106 **
	WT/C.I.D.				22.4**		22.4**
	AXLE RATIO				3.90 **		3.90 **
OTHER IMPORTS	% SALES			1.6%	7.9 %		9.5%
	FUEL ECON			16.1**	17.4 **		17.2**
	INERTIA WT			3050**	2525 **		2613**
	C.I.D.			121**	104 **		107**
	WT/C.I.D.			25.2**	24.3**		24.4**
	AXLE RATIO			4.10**	3.68 **		3.75**
TOTAL DOMESTIC	% SALES	27.8%	17.2%	15.8%	10.4%	12.5%	83.7%
	FUEL ECON	9.2	9.7	14.6	19.0	10.3	10.9
	INERTIA WT	4884	4292	3522	2908	4283	4169
	C.I.D.	403	325	260	153	342	320
	WT/C.I.D.	12.1	13.2	13.5	19.0	12.5	13.5
	AXLE RATIO		2.91	3.18	3.06	3.10	3.07
TOTAL IMPORTS	% SALES			1.6%	14.7%		16.3%
	FUEL ECON			16.1	18.9		18.6
	INERTIA.WT			3050	2450		2509
	C.I.D.			121	102		104
	WT/C.I.D.			25.2	24.0		24.1
	AXLE RATIO			4.10	3.79		3.82
ALL	% SALES	27.8%	17.2%	17.4%	25.1%	12.5%	100%
	FUEL ECON	9.2	9.7	14.7	18.9	10.3	11.8
	INERTIA WT	4884	4292	3506	2642	4283	3904
	C.I.D.	403	325	260	123	342	287
	WT/C.I.D.	12.1	13.2	13.5	21.5	12.5	14.9
	AXLE RATIO		2.91	3.18	3.48	3.10	3.17

Source: Sales & specs from Automotive News *7 months ** Estimate

Vehicle weight has also increased over the past years, both on an individual model basis and for the market as a whole. This is also in the direction of poorer fuel economy.

The installation of power consuming accessories has also increased over the past years. This is also in the direction of reduced fuel economy.

2.3.1.4 How Much Have We Lost? - How much today's fuel economy has decreased depends on the comparison year selected. DOT's figures indicate a decreasing trend from the earliest data on record in terms of fleet average fuel economy. For the purposes of this report, 1967 has been chosen as the comparison year, since nationwide emission standards went into effect in the next model year and most nation-wide safety requirements also were required after that year.

Considering all of the trends and factors discussed in this section, the change in fleet average fuel economy since 1967 has been approximately a 4% loss, and the change in new model fuel economy has been approximately a 12% loss. The fleet average fuel economy is higher than the new model fuel economy, since many of the vehicles on the road are older models with their higher fuel economy.

3. APPROACH

3.1 DESCRIPTION OF THE METHODOLOGY

The approach used in this study was as follows:

1. Examine the current information and literature in the fuel economy and fuel economy improvement area with emphasis on the recent studies performed by A.D. Little (ADL) and Southwest Research Institute (SwRI) for the Department of Transportation (DOT), and the Environmental Protection Agency (EPA);
2. Prepare a detailed list of questions which was sent to several auto makers after which meetings were held with representatives of the manufacturers to discuss their responses to the questions, receive their comments on the ADL and SwRI reports and to explore with them the magnitude and feasibility of the various fuel economy improvements under consideration;
3. Develop quantitative estimates of practical individual fuel economy improvements, their cost and the lead time for their introduction, and their likely safety and emissions impacts;
4. Estimate the likely fuel economy performance of vehicles that could be introduced into the marketplace by 1980.

The assumptions, results and conclusions of this process are described below.

3.2 ASSUMPTIONS AND CONSTRAINTS

3.2.1 Assumptions

a. The weighted harmonic sum of the urban and non-urban fuel economy was used as the measure of fuel economy by the panel. The EPA 1975 Federal Test Procedure was the measure of city fuel economy and the EPA Non-Metropolitan Driving Cycle was the measure of highway fuel economy. These two measures are abbreviated FTP and HWC (for "Highway Cycle") reflecting the popularized names generally associated with these cycles. The overall fuel economy, abbreviated $\overline{mpg}$, is defined as the fuel economy obtained by weighting the FTP and HWC miles per gallon 55% and 45%, respectively, to obtain the proper ratio of miles driven in urban and non-urban operation. In equation form:

$$\overline{mpg} = \frac{1}{\frac{.55}{FTP} + \frac{.45}{HWC}}$$

b. "Market Demand" must be met. That is, a large number of vehicles, of the order of ten million, must be available for sale to meet expected demand in 1980 and continually in earlier and later years.

c. In 1980 the types of automobiles available for purchase will span essentially the same functional range as is available today, that is, vehicles ranging from those able to carry 6 passengers and their luggage to those able to carry 4 passengers and their luggage.

d. For the purposes of this study three functional classes of automobiles are adequate for projection.

3.2.2 Constraints

a. A major constraint in this study was the lack of information about the plans of the manufacturers and the decisions that have already been made that will affect the types of vehicles that will be available between now and 1980.

b. The panel has made estimates of the improvements in fuel economy that might be achievable in a typical car of a given size class, but in practice the improvements in fuel economy may be somewhat different for cars in the same size class that deviate from the norm of the typical design.

c. This panel has assumed that manufacturers would require sufficient development and testing of their production prototypes to ensure that the quality of the future production models in terms of durability, reliability, maintainability and drivability would be approximately equivalent to the quality of production cars of the present design.

3.3 DESCRIPTION OF VEHICLE SIZE CLASSES

3.3.1 Passenger Cars

Currently, automobile industry publications subdivide passenger cars into several different categories. Usually these classes are used to describe domestic vehicles. These classes and some of their pertinent characteristics are listed in the following tables.

TABLE 3-1 1973 MODEL YEAR SALES AND TYPICAL SPECIFICATIONS
(TOTAL SALES: 10,739,541 UNITS)

SUBCOMPACT 2,383,844 units (22% of total)	WB 96", L 169", W 65", H 54", CID 122, 4 cyl., WEIGHT: 2283 lbs. INERTIA WEIGHT: 2500 lbs. (typical) COST: $2448, RADIO, NO POWER OPTIONS, SEDAN, 2 DR.
COMPACT 1,939,651 units (18% of total)	WB 109", L 193", W 72", H 52", CID 231, 6 cyl., WEIGHT: 3035 lbs. INERTIA WEIGHT: 3500 lbs. (typical) COST: $2649, RADIO, AUTO. TRANS., POWER STEERING, SEDAN, 2 DR.
INTERMEDIATE 2,528,114 units (24% of total)	WB 115", L 211", W 78", H 53", CID 305, V-8, WEIGHT: 3789 lbs. INERTIA WEIGHT: 4000 lbs. (typical) COST: $3274, RADIO, AUTO. TRANS., POWER DISK BRAKE, POWER STEERING, SEDAN, 2 DR.

TABLE 3-1 1973 MODEL YEAR SALES AND TYPICAL SPECIFICATIONS (TOTAL SALES: 10,739,541 UNITS) (Cont.)

STANDARD 2,989,708 units (28% of total)	WB 123", L 223", W 80", H 55", CID 359, V-8 WEIGHT: 4351 lbs. INERTIA WEIGHT: 4500 lbs. (typical) COST: $4081, RADIO, AIR COND., POWER DISK BRAKE, POWER STEERING, SEDAN, 2 DR.
LUXURY 898,194 units (8% of total)	WB 127", L 228", W 80", H 55", CID 461, V-8, WEIGHT: 4892 lbs. INERTIA WEIGHT: 5500 lbs. (typical) COST: $6250, RADIO, AIR COND., POWER DISK BRAKE, POWER STEERING, SEDAN, 2 DR.

TABLE 3-2 VEHICLE CLASSIFICATIONS

STANDARD SIZE CLASS

- BUICK (LESABRE, CENTURION)
- CHEVROLET (IMPALA, BISCAYNE, BEL AIR)
- CHEVROLET (CAPRICE)
- CHRYSLER (EXCLUDING IMPERIAL)
- DODGE (POLARA, MONACO)
- FORD (GALAXIE, CUSTOM)
- MERCURY (MONTEREY)
- OLDS (DELTA 88)
- PLYMOUTH (FURY, GRAN SEDAN)
- PONTIAC (CATALINA, BONNEVILLE, GRAND VILLE)
- MURCURY (COUGAR)
- FORD (LTD)
- AMC (AMBASSADOR)

INTERMEDIATE SIZE CLASS

- AMC (MATADOR)
- CHEVROLET (CHEVELLE)
- FORD (TORINO)
- CHEVROLET (MONTE CARLO)

TABLE 3-2 VEHICLE CLASSIFICATIONS (Cont.)

INTERMEDIATE SIZE CLASS (Cont.)
- MERCURY (MONTEGO)
- PLYMOUTH (SATELLITE)
- BUICK (CENTURY)
- OLDS (CUTLASS)
- PONTIAC (LE MANS)
- PONTIAC (GRAND PRIX)
- DODGE (CORONET AND CHARGER)

COMPACT SIZE CLASS
- AMC (HORNET)
- CHEVROLET (NOVA)
- DODGE (DART, DEMON, CHALLENGER)
- FORD (MUSTANG)
- FORD (MAVERICK)
- MERCURY (COMET)
- PLYMOUTH (VALIANT)
- PONTIAC (VENTURA)
- CHEVROLET (CORVETTE)
- PLYMOUTH (BARRACUDA)
- PONTIAC (FIREBIRD)
- CHEVROLET (CAMARO)
- AMC (JAVELIN)

SUBCOMPACT SIZE CLASS
- FORD (PINTO)
- CHEVROLET (VEGA)
- AMC (GREMLIN)
- VOLKWAGEN
- TOYOTA
- DATSUN
- FORD (CAPRI)
- BUICK (OPEL)
- DODGE (COLT)

TABLE 3-2 VEHICLE CLASSIFICATIONS (Cont.)

LUXURY SIZE CLASS

BUICK (RIVIERA)
CADILLAC (ELDORADO)
OLDS (TORONADO)
LINCOLN (MARK IV)
MERCURY (MARQUIS)
OLDS
OLDS (98)
LINCOLN (CONTINENTAL)
CHRYSLER (IMPERIAL)
BUICK (ELECTRA 225)
CADILLAC
FORD (THUNDERBIRD)

All U.S. automobile manufacturers use body size as the parameter which differentiates one class of car from another. Chrysler manufactures A, B, and C size bodies corresponding to compact, intermediate, and standard size bodies respectively. General Motors manufacturers A, B, and C bodies, and Ford X and H size bodies corresponding to intermediate, standard, and luxury/specialty, compact and subcompact size cars respectively. Ford and American Motors use similar systems to identify body size with car class.

Generally cars having the same body or the same size body are manufactured in the same plant because they can be made with the same body assembly tooling or on the same line. For example, GM makes Pontiac, Buick, and Oldsmobile standard size cars at the Fairfax, Kansas plant on the same assembly line; Ford manufactures Maverick and Comet on the same line in Kansas City; and Chrysler makes Dart and Valiant on the same line in Hamtramick, MI.

Mixtures of body sizes occur sometimes when production of a particular model at a plant is insufficient to fill the plant. Ford makes Thunderbird, Lincoln and Mark IV at Wixom, MI., each with a production of less than 50,000 units. This will require separate body assembly, tooling for each body size or configuration. However the vehicle assembly line may be common to all the body assembly lines.

The cars manufactured in each body size carry the traditional names that we associate with luxury, standard, intermediate, compact and subcompact size cars. Major body changes generally occur at fairly long intervals of the order of twelve years. In 1974, the Ford Mustang received its first major change since the early 1960's. These changes are infrequent due to the huge investment in tooling required by each manufacturer in body assembly tooling. This investment is of the order of $40 to $80 million for each body size and body type and for each increment of 200,000 units of production of each body for a total investment in the U.S. of the order of $4 billion.

Dimensionally these body sizes have varied over the years but in terms of their trade names and functional capacity they have remained the same. In order to account for the manufacturing facilities, tooling, capital investment and labor and material required to produce the automobile fleet and to assess the changes required to convert from one configuration to another or from one class to another it is necessary to classify cars in accordance with body size which identifies with a particular set of tooling and investment.

The above vehicle classes are used to group vehicles for sales and marketing purposes, primarily. After careful consideration it was decided not to use the current definitions of vehicle class for this study for the following reasons:

a. The current classification scheme for passenger cars only indirectly groups cars by their function, i.e., the ability to carry passengers and luggage, because the current classification scheme primarily uses a wheelbase-related definition.

b. The characteristics of the passenger cars in the current classes change with time. The specifications of vehicles in each class are not the same over a given time period as the following example shows.

Some of the sales-weighted parameters of the "standard" size vehicle are listed below.

	'58 Std.	'73 Std.	4-door '73 Inter.
Curb Wt.	3900 lbs.	4700 lbs.	4000 lbs.
Wheelbase	119"	123"	117"
Width	78"	79"	78"
Length	209"	225"	208"
Overhang	89"	102"	95"

The "standard" vehicle of 1958 was much closer to 1973's 4-door "intermediate" than it is to 1973's "standard" in almost every category. Because of the changing trend for vehicles of the same name, it was decided to use a functional definition, since the important characteristic of the "standard" size vehicle, for example, that has remained most constant over the years is its ability to carry six people.

c. The current classification scheme lumps together vehicles with radically different characteristics into the "specialty/luxury" class, because that is what is left over when the other classes are grouped. For example, the "specialty/luxury" class includes both the Continental Mark IV and the Corvette which are markedly different.

d. Imported cars grouped into the same classes as the current ones used for domestic vehicles result in functionally different vehicles being lumped together. For example, the trade journals sometimes put all imports into one classification regardless of their function because the reason for grouping vehicles has historically been to keep track of sales in given domestic vehicle classes.

For the above reasons a functional class definition has been used, grouping vehicles into three different size classes, based on their passenger carrying capability. The three functional classes and their descriptions are listed below:

	Large Size	Mid-Size	Small Size
No. of passengers	6	5	4
Current vehicle classes incl.	Std. & some spec., no imports	Inter. & compacts, some spec., some imports	Subcompacts most imports
Approximate % of current market (1974)	27%	45%	28%

3.3.1.1 Large Size - The large (LS) class is where most of the "standard" or "full-size" vehicles are today. The terminology "Large" was chosen to reflect the fact that the passenger carrying capacity is the largest of the three classes. This class includes such vehicles as the Chevrolet Impala, the Ford Galaxie, and the Plymouth Fury, for example. It also includes vehicles that are larger in size such as Cadillacs and Lincolns, but no vehicles that are smaller.

3.3.1.2 Mid-Size - The mid-size (MS) class includes the Chevrolet Chevelle and Nova, the Ford Torino and Maverick, the Plymouth Satellite and Valiant, and the Audi 100LS, for example. This class is the broadest one currently. It is recognized that for certain safety requirements, i.e., the number of seal belts and the capacity labeling for Federal Motor Vehicle Safety Standard (FMVSS) 104, many of these intermediate and compact vehicles are rated as six passenger. However, the functional size classification chosen for this study attempts to group vehicles based on some sort of subjective comfort/room criteria for the passengers carried, so these vehicles were put into the mid-size, 5-passenger class.

3.3.1.3 Small Size - The small size class includes the Chevrolet Vega, the Ford Pinto, the Dodge Colt, the AMC Gremlin, and the Volkswagen Dasher, for example. These vehicles offer varying amounts of room inside, but are all considered nominally 4-passenger vehicles for the purposes of this study.

3.3.1.4 Classes Not Specifically Considered -

a. Station Wagons - These vehicles are available in all three size classes today, and are basically derivatives of their sedan counterparts. No special class for these vehicles, which may have greater passenger and luggage carrying capacity than their sedan counterparts was made because most of the improvements to the basic sedans will be carried over into the station wagons to varying degrees, and, thus, the station wagons were not considered separately.

b. Two-Passenger Vehicles - This class which currently includes most sports cars, was not included because most of the engine-related improvements can be carried over into this class and because the sales of this class are relatively small.

c. Mini-Size Vehicles - This class of vehicles which could be considered to be smaller than the small size used in this study was given careful consideration. This class of vehicles appears to be developing world-wide (except in the U.S.) as a new class of vehicles that are rather similar in concept. These type of vehicles use a transversely mounted engine in the front with front wheel drive. This allows for a very compact overall size and light weight in relation to the number of passengers (usually four) carried. This type of vehicle was introduces in Great Britain more than ten years ago by what is now British Leyland and was called the Mini.

   Vehicles of this configuration are being produced currently in Great Britain, Italy, Germany, France and Japan. An-example of this type of vehicle currently sold in the U.S. is the Honda Civic. This class was not considered separately because of the lack of information concerning any of the major U.S. manufacturer's plans to produce or import such vehicles. These types of vehicles were grouped with the small cars.

3.3.2 Light Duty Trucks

Six basic types of light duty truck-type vehicles were considered; the small pick-up, the large pick-up, the small van, the large van, utility vehicles, and truck/wagons.

a. Small Pick-up - Examples of vehicles in this class are the Toyota, Nissan, and Mazda pick-up trucks and the Chevrolet LUV and the Ford Courier made for GM and Ford by Isuzu and Mazda, respecitvely.

b. Large Pick-up - This is the typical domestic pick-up truck, the Ford F-100, for example.

c. Small Van - The only example in this class is the VM Microbus.

d. Large Van - This class includes the Dodge Sportvan, for example.

e. Utility Vehicles - This class includes the Ford Bronco, for example.

f. Truck/Wagons - This class is the pick-up truck-derived station wagon, an example of which is the IH Travelall.

The projected sales increase of these light duty vehicle types indicate it is appropriate to include only the pick-up class for special consideration. Generalized fuel economy extrapolations may be made for other classes.

4. EVALUATION OF INDIVIDUAL TECHNOLOGIES

4.1 VEHICLE IMPROVEMENTS

The power required to propel a car on a level road is needed to overcome three things:

a. aerodynamic drag,
b. rolling resistance,
c. inertia.

The fraction of the total power requirement that is used to overcome each of these is highly dependent on the particular driving condition. During steady state cruising, no power is required to overcome inertia while during full power accelerations from a stop, almost all of the power required is to overcome inertia. During low speed cruises most of the power is required to overcome rolling resistance with almost none required for aerodynamic drag. At higher speed conditions aerodynamic drag exceeds rolling resistance. They are about equal at cruise speeds of approximately 55 mph.

As an example of where the total fuel energy goes in a typical gasoline engine, Ford Motor Co. Technical Memorandum PRM-66-27 (9/1/66) gives the following estimates for "city route" and 50 mph cruise:

	City Route % of Higher Heating Value	50 mph % of Higher Heating Value
Lower Heating Value	6.5	6
Incomplete Combustion	12.5	6
Dissoc, and Changing Specific Heats	11.0	9
Otto Cycle Inefficiency	32.5	35
Finite Combustion	2	2
Heat Transfer from Cylinder	9	10
Pumping	4	6
Mechanical Friction	4.5	6
Engine BHP	18	20

Thus a typical gasoline engine is seen to be less than 20% efficient and the overall fuel use efficiency is even lower if transmission losses are considered.

DOT[1]* computer simulations for a typical standard size car show the following breakdown of vehicle energy (HP-HR) use during driving cycles represented by the EPA Urban (EPAU) and Highway (EPAH) cycles:

TABLE 4-1 ENERGY LOSSES - EPA URBAN AND HIGHWAY DRIVING**

	EPAU % HP-HR	EPAH % HP-HR
Accessories	4.93	3.87
Transmission	20.05	11.60
Rolling Resistance	31.55	36.58
Aerodynamic Losses	16.77	43.67
Braking	26.71	4.28

Also for the above EPAH and EPAU Cycles the following applies:

TABLE 4-2 EPA URBAN AND HIGHWAY DRIVING STATISTICS

	EPAU	EPAH
Time-sec.	1372	756
Distance-miles	7.5	10.2
Energy-HP/HR	3.84	4.88
Fuel-lbs.	4.39	3.89
Ave. mph	19.6	48.7
HP/HR/mile(ave.)	.51	.48
Ave. BSFC-lbs./HP/HR	1.14	0.8

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*Superscripts indicate reference number as listed on pages R-1 and R-2 at the end of this report.

**Cold start not considered.

TABLE 4-2 EPA URBAN AND HIGHWAY DRIVING STATISTICS (Cont.)

	EPAU	EPAH
MPG*	10.82	16.72
% Fuel During Cruise	33.1	86.9
% Fuel During Acceleration	36.6	10.0
% Fuel During Deceleration	16.5	3.1
% Fuel During Idle	13.7	0
% Fuel During Closed Throttle Deceleration	13.5	3.1

Reducing the power requirements of a vehicle will tend to increase fuel economy, however, during some conditions the reduction in power requirement may be more than offset be a reduction in the efficiency of engine operation. For conventional engines the efficiency of operation increases with load up to a point between 1/2 and full power. Unless the technique used to reduce vehicle power requirement allows the engine to be re-sized to the vehicle the benefits in fuel economy will not be as great as the reduction in power requirement. The effect of this phenomenon is shown in Figure 4-1, which is a "map" of a typical gasoline engine. Plotted over the range of possible loads break mean effective pressures (BMEP) and speeds the engine can encounter are BSFC contours. BSFC or brake specific fuel consumption is the pounds of fuel required to produce each unit of horsepower output for an hour. For a given power requirement the lower the BSFC of the engine the higher will be the fuel economy. Superimposed on the map is a "road load" curve. At 70 mph, for example, the BSFC of this particular engine would be just over .55. It can also be seen from the map that the horsepower output of the engine is about 60 and the rpm is about 2600.

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*Cruise mode includes accelerations lower than 0.5 - 1.0 feet per second squared (depending on drive cycle segment).

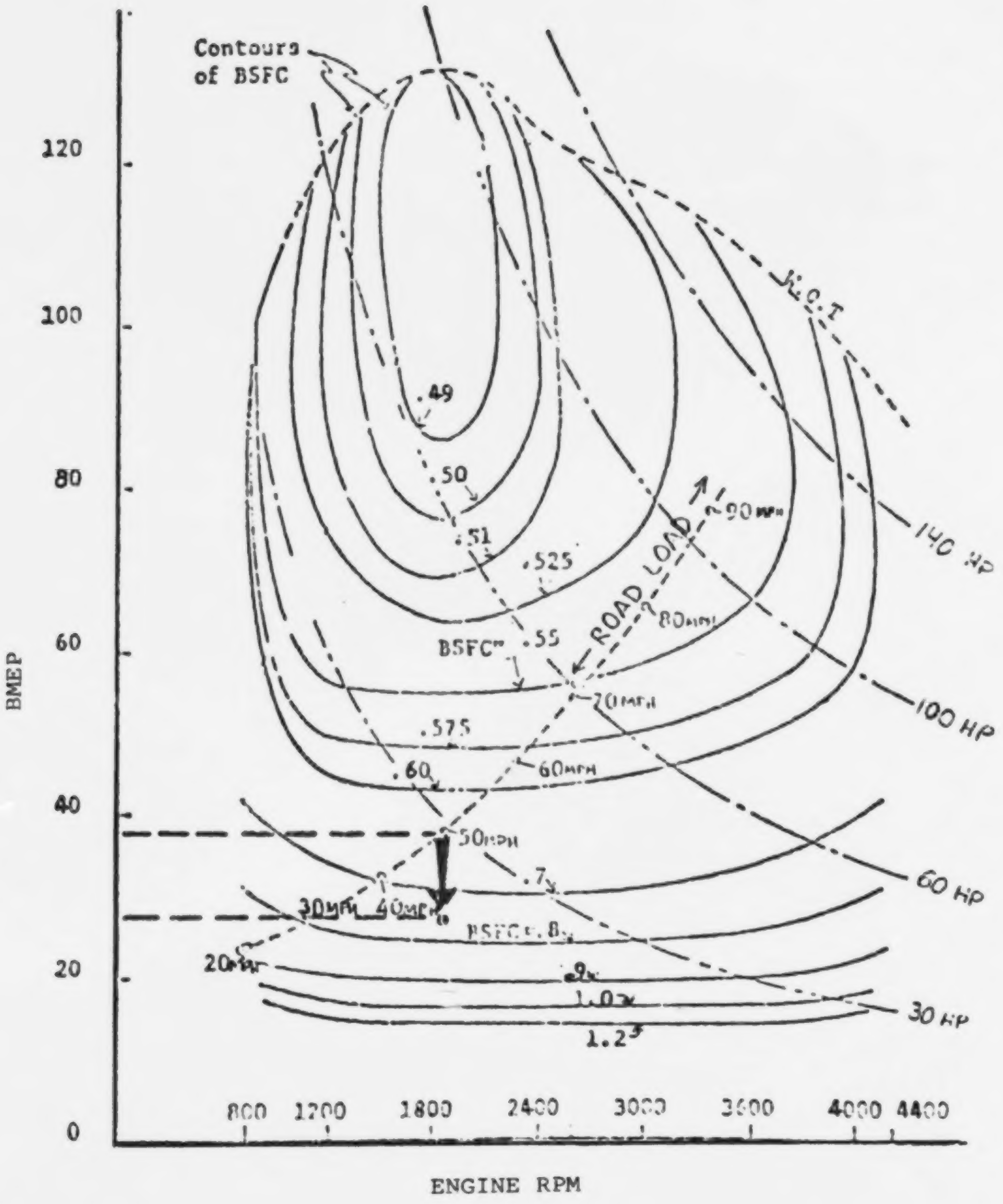


Figure 4-1 Performance Map - Typical Gasoline Engine

Consider then the effect of reducing the road load power requirement at a given speed. At 50 mph it can be seen from Figure 4-1 that the BSFC of the engine is about .65. If aerodynamic drag or rolling resistance changes were made to the vehicle such that the power requirement was reduced by 25%, the reduction in fuel consumed would not be as great a 25% because the BSFC would not remain constant. The arrow on Figure 4-1 shows what would happen to BSFC. Engine rpm would be equal (assuming no drive line changes) but since the BMEP is now 25% lower, the new BSFC condition is about .76, 13% higher than it was before. The relative consumption is .84 (.75 x 1.13) or a 16% decrease due to the 25% drop in power requirement.

If an engine size reduction accompanies a reduction in power requirement then essentially the same BMEP and BSFC can be maintained. The result is a 25% reduction in fuel consumption for a 25% reduction in power requirement.

The size of a passenger car's engine is determined primarily by the desired acceleration performance, not the maximum steady state cruise speed. Expressway cruising speeds are achieved with but a fraction of maximum engine power. The power required to accelerate the vheicle is determined primarily by the vehicle's mass. Aerodynamic and rolling resistance characteristics have only a small effect comparatively. Therefore, reductions in aerodynamic drag and rolling resistance only do not allow significant reductions in engine size.

The table below shows this effect:

TABLE 4-3 EFFECT ON 0-60 MPH ACCELERATION PERFORMANCE OF REDUCTIONS IN WEIGHT, DRAG AND ROLLING RESISTANCE[4]

Parameter Reduced by 10%	% Improvement in Accel. Time
Aerodynamic Drag	1%
Rolling Resistance	1%
Weight	10%

Without reducing engine size the reductions in vehicle power requirements caused by improvements in aerodynamic drag and rolling resistance will usually be partially offset by a reduction in engine efficiency since the engine will be operated at a point which is further away from the optimum efficiency point.

A 10% reduction in weight would allow the engine to be resized so that reductions in vehicle power requirement due to the weight loss would not be offset by the engine having to operate further from the high efficiency area. 10% reductions in aerodynamic drag and rolling resistance, however, do not increase the acceleration performance of the vehicle to the extent that the engine size could be reduced significantly.

4.1.1 Vehicle Weight Reduction

As discussed above the greatest potential for economy improvements lie in the weight reduction area because not only do weight reductions lessen the power demanded of the engine they allow resizing of the engine so that it can be operated nearer its best efficiency point. Reducing vehicle weight not only lessens the power required to accelerate the vehicle but also cuts rolling resistance.

To maximize the benefits of a weight reduction it is desireable to reduce the engine size until acceleration performance is returned to the original level. Figure 4-2 illustrates the difference between weight reduction with and without engine resizing. The estimates shown in Figure 4-2 are based on a regression of data from all EPA certification tests of 1973 models. A 38% weight reduction without a re-optimization of engine size for constant performance results in approximately a 12% increase in fuel economy. Re-sizing the engine increases fuel economy by about 26%.

Table 4-4 shows the effect of a 10% weight reduction as reported by several sources:

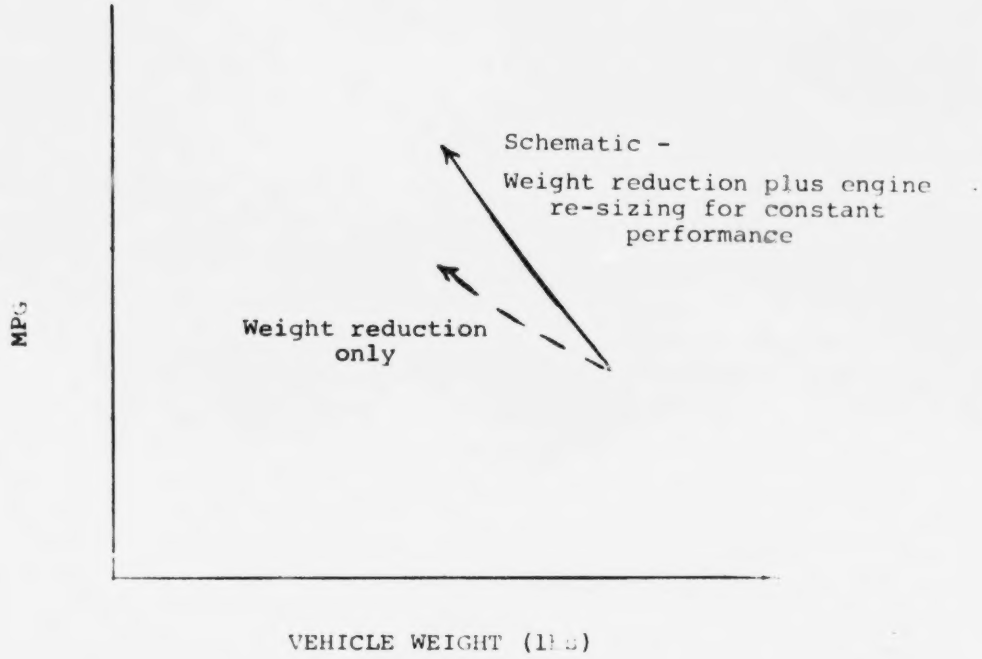


Figure 4-2 Effect of Weight Reduction on Fuel Economy

TABLE 4-4 ESTIMATED IMPROVEMENT IN ECONOMY (4000 lb. Car) WITH 10% WEIGHT REDUCTION

Source	Weight Only	Re-optimized
DOT Computer Simulations	2.6%	6.8%
EPA Regression	3.3%	11.2%
SwRI Estimate[2]	5.6%	---
GM *	2.8%	---
ADL[3]	3.5%	5.5% **
Huebner-Gasser[4]	4.3%	---

*Based on 7 gal/10,000 mi./100 lb. factor

**Optimized by changing rear axle ratio, not engine size

The reduction of vehicle weight accompanied by resizing the engine to maintain constant performance (acceleration capability) will improve vehicle fuel economy. Sensitivity is defined as percent change in fuel economy divided by the percent change in weight. Typical sensitivities of fuel economy to weight changes for several vehicles while maintaining constant performance are as follows (based on DOT computer simulations):

TABLE 4-5 FUEL ECONOMY SENSITIVITY TO WEIGHT

Vehicle Weight (Lbs.)	Engine Displacement (Cubic Inches)	Sensitivity
2000	100	.56
2750	140	.52
3000	155	.63
3000	250	.67
3500	250	.71
3500	318	.72
4000	350	.64
4500	350	.79
4500	350	.77
5000	400	.83

There are three fundamental approaches, open to a manufacturer to achieve a weight reduction:

a. Materials substitution
b. Reduction in car size
c. Chassis redesign

Materials substitution involves the replacement of certain components with functionally equivalent components of different composition. Prime candidates for expanded usage in a weight reduction effort would be aluminum, plastic and high strength low alloy (HSLA) steel. Potential uses of these materials in a weight reduction program are shown in the following table:

TABLE 4-6 MATERIALS SUBSTITUTION POTENTIAL SAVINGS

Material	Usage	Potential Savings (lbs.)
Plastic	Wheels	100[2]
Aluminum	Hood, trunk lid, doors, fenders, bumpers, misc.	450[1]
Aluminum	Engine block	80
Aluminum	Cylinder heads	40
Aluminum	Intake Manifold	20
HSLA, Al, Plastic	Bumpers	130

HSLA also appears to have considerable potential in the area of unibody structure and frames for body/frame cars. Weight reductions in the range of 600 lbs. appear feasible without resorting to aluminum engine blocks or cylinder heads and without taking advantage of the further weight reductions that could be achieved by re-optimizing the components that were not replaced but are subjected to lower stress due to the lighter overall vehicle weight.

Average car weight can also be reduced without material replacement or redesign if a manufacturer merely shifts his production to favor the smaller vehicle classes. This method of reducing average vehicle weight is, however, highly dependent on market demand since the functional capabilities (ability to carry people and luggage) are usually reduced with this approach. An example of this type of shift would be a manufacturer converting a full-size car line to a mid-size line as Ford and GM did this past winter.

Of all weight reduction approaches, chassis redesign appears to offer the greatest potential improvement, at least for U.S. manufactured cars. Hogg[5] showed that a new European subcompact designed for the U.S. market had essentially equivalent room for the front seat passengers as a recently introduced domestic subcompact but the European car had:

- 14% more rear leg room
- 25% more rear shoulder room
- 125% more luggage room
- 27% less weight

Larger European sedans demonstrate equally impressive advantage over their domestic counterparts. Major reasons for the substantial advantages shown by European cars in this area are:

a. Increased use of unibody construction

b. Increased use of front-wheel drive

c. Increased use of independent rear suspensions (IRS)

d. Exterior dimensions held to those required to enclose passengers, power train, and trunk; rather than set by styling constraints

Front wheel drive (FWD) and IRS usage are both space saving techniques. FWD makes for more efficient use of the space available by concentrating the complete engine and drivetrain assembly at one end of the vehicle thereby obviating the need to transmit power to the rear of the vehicle through a long and space consuming driveshaft.

IRS saves space by eliminating the volume normally allocated for upward movement of the rear differential. With IRS the rear differential is fixed and each drive wheel is "independently" connected to the differential through a pair of U-joints. IRS is generally associated with improved ride quality due to the high wheel travel (and, therefore, soft springing) made possible with its use. IRS is common on luxury cars such as the Mercedes-Benz.

A closer to home example is available for the effect of "European" vs. U.S. design philosophy when the new Ford Granada is compared to the Ford Torino. The boxier styling which has been incorporated in the Granada has achieved nearly equal interior room to the Torino at an 800 lb. advantage in weight.

The panel feels that the design change approach will have the greatest potential for weight reduction in model year 1980 and beyond. An example of what can be accomplished with the vehicle re-design approach can be seen in Table 4-7.

A survey of the currently available vehicles reveals that some cars are more weight efficient than others. Most of the vehicles listed in Table 4-7 have more interior room than the average car in their class even though the weight is substantially less than the average. In the large size class there were no vehicles that appeared to be really weight efficient, but a review of dimensional specifications of some mid-size cars indicated that the only dimension which kept them from being classified as a "large" vehicle was their width. With 10% added to the width of some five-passenger sedans, passenger accommodations become nominally equivalent to today's large cars. The engine currently used in the mid-size car selected for illustrative purposes as a candidate for widening (Table 4-7) was sufficiently powerful to provide typical larger car power to weight ratios even when the weight of the vehicle was increased by 10% to account for a 10% change in width (No cost data was generated for such a design).

Considering the 1980 timeframe, weight additions were assumed to account for additional safety/damagability requirements and further engine modifications and emission control devices. The additional weight for future engine modifications includes allowances for catalysts, start catalysts, air pumps, air injection modulation, etc. The safety/damageability weight increases account for MVSS 215 Title I exterior protection, MVSS 208 (occupant crash protection), MVSS 105 (Brakes) and MVSS 202-207 (seat structures and head restraints). These weight increases are in line with recent projections made by General Motors.[6]

Weight increases applied to the 1974 examples of weight efficient vehicles results in inertia weight classes for the weight efficient cars of the '80's of 2500, 3500 and 4000 pounds respectively for small, mid-size and large cars. As shown in Table 4-8, weight reductions of approximately 20% across the board would be possible with this design approach.

TABLE 4-7 WEIGHT EFFICIENT VEHICLES

	Small Car Weight (lbs)	Mid-Size Car Weight (lbs)	Large Car Weight (lbs)
Model	Audi Fox, 2100 Dodge Colt, 2300 Fiat 128, 1980 Fiat 124, 2320 Honda Civic, 1720 Renault 12, 2230 Toyota Corona, 2315 VW Dasher, 2100	Volvo, 142, 2885 Audi 100, 2600 Saab 99, 2610 BMW Bavaria, 3375 Mercedes 230, 3150 Peugeot 504, 2775 Toyota MkII, 2820	Volvo 164 widened by 10%
Average Curb Weight	2133	2888	3550
Inertia Weight	2500	3000	4000
Add for Safety/ Damageability	100	150	200
Add for Future Engine Mods	60	70	80
Average Curb Weight (1980)	2293	3108	3830
Inertia Weight	2500	3500	4000

TABLE 4-8 INERTIA WEIGHT COMPARISON OF VEHICLE TYPES

	Small	Mid-Size	Large
Typical 1974	3000	4250	5000
Weight Efficient 1980	2500	3500	4000
Weight Change Possible	-500	-750	-1000
Percent Weight Change	-17%	-18%	-20%

An example of how the weight efficient vehicle of the 80's could compare with a more typical 1974 car is shown in Figure 4-3. Both of these vehicles are in the mid-size class and are in production today. As can be seen from the figure, however, it is their interior size rather than exterior size which results in their being grouped together.

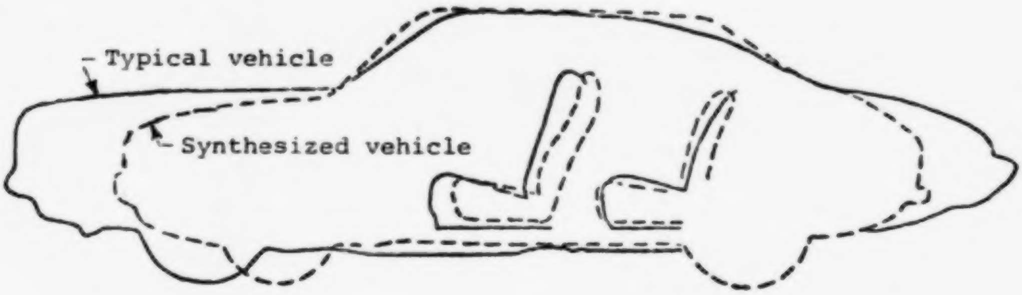


Figure 4-3 Synthesized Versus Typical Vehicle

	Synthesized	Typical
Seating capacity, nominal qualifications	5 none	5 inadequate rear headroom
Curb weight, lbs.	2,610	4,300
Power to weight ratio, hp/lb	.044	.040
Usable trunk space, cu. ft.	16.9	15.7
Average fuel economy, mpg	20.6	10.4

Attempts to project the capability of the various manufacturers to accomplish significant weight reductions by 1980 were frustrated by the unavailability of information relating to manufacturers current plans. Decisions which have already been made greatly affect what can be accomplished by 1980. While sufficient lead time remains for complete vehicle redesigns on some models by 1980 it does not appear that the tooling capability exists to do this for every model. The capacity exists for each manufacturer to make a major change in one body size each year. It does appear however steps have already been taken which will result in some "larger" cars being halfway between where they are now and where they can be as shown in Table 4-8. GM for example, has reported (FEA)[6] being well on their way to getting 400 pounds out of their large cars by 1977. The panel has concluded that what GM has planned for 1977 on their large car can (≈ 10% reduction in weight) also be done by 1980 on the other large and mid-size cars which are not currently weight efficient. This leaves options open to each manufacturer. If the manufacturer chooses not to redesign by 1980, he can concentrate on materials replacement. It is likely that many models will be given a little of both approaches.

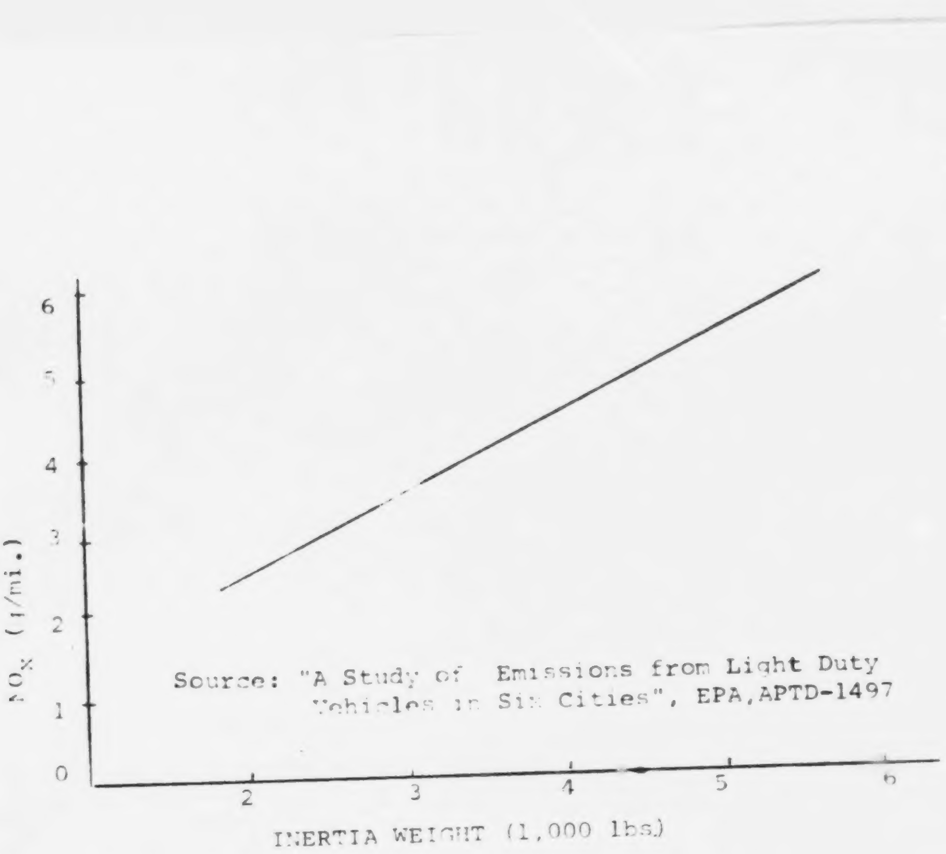
Not assuming as great a weight change by 1980 as has been shown to be technically feasible from Table 4-8 also greatly reduces the risk that the weight efficient vehicle might not be "in demand" because of major styling changes.

4.1.1.1 Emissions Impact - A large base of data is available which leads one to the conclusion for uncontrolled or partially controlled cars that weight and exhaust emissions are directly correlated. It is of critical importance to note that this relationship is only applicable to uncontrolled or partially controlled cars. When standards of performance are introduced, extreme caution must be exercised in the use of this relationship to describe trends.

Consider Figure 4-4. This is a plot of NO_x exhaust emissions vs. vehicle weight for uncontrolled cars. The trend is clear; heavier cars have higher emissions. Interpreting the meaning of this relationship, however, is not easy. This relationship does not mean that heavier cars will always emit more NO_x. It only indicates that it will probably be more difficult to reduce NO_x emission to a fixed level for a heavy car than for a light car. This is not to say that a heavy car won't be able to achieve any particular emission standard or goal just because it is heavier. It will be more difficult, however.

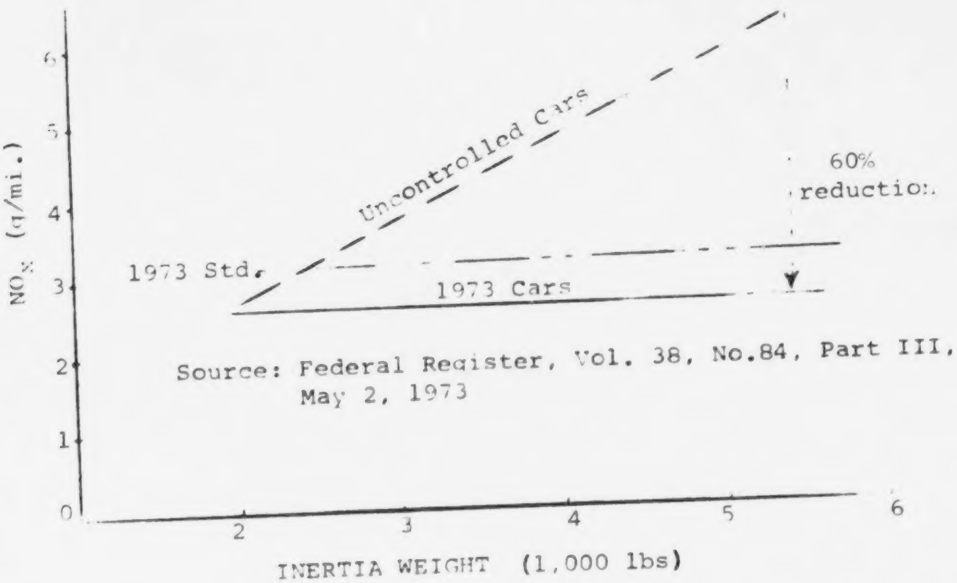
Figure 4-5 shows what has actually happened to NO_x emissions since the advent of emission controls. The NO_x vs. weight trend is gone. It is gone because the emission standards require that all cars be equally non-polluting regardless of their weight. The technology was available to make all cars achieve the standard and so all cars did, with about the same margin of safety. This meant that the manufacturers had to do essentially nothing on light cars and make substantial improvements on heavy cars. The more stringent NO_x standard of 2.0 gpm that California established for 1974 meant that manufacturers of light cars also had to achieve reductions from uncontrolled levels and manufacturers of heavy cars had to do even more. Since all manufacturers were targeting for the same standard again, however, no trend in NO_x emissions vs. weight is apparent. The general impact of weight reduction on emissions will, therefore, be that it will be easier for a manufacturer to meet the Federal emission standards, whatever they are. There will be fewer trade-offs, be they cost or driveability or whatever, that will have to be made.

4.1.1.2 Natural Resources Impact - The natural resources impact of vehicle weight reduction will depend on the particular approach used. Every approach will result in a beneficial impact on ferrous metals. The re-design approach will not adversely impact any resource. Materials substitution, however, will increase the aluminum per car required and increased use of plastics will impact the petroleum industry.



Source: "A Study of Emissions from Light Duty Vehicles in Six Cities", EPA,APTD-1497

Figure 4-4 NO_x Emissions Versus Weight (Uncontrolled Cars)



Source: Federal Register, Vol. 38, No.84, Part III, May 2, 1973

Figure 4-5 NO_x Emissions Versus Weight (1973 Cars)

4.1.1.3 Safety Impact Due to Weight Reductions

When there is no requirement that cars be equally safe the heavy cars show a safety advantage due primarily to its larger crush distance. Figure 4-6 shows the classical relationship between weight and safety. Drivers of vehicles in the 2000-2499 lb. category (sub-compact) had nearly three times the percentage of serious and fatal accidents per mile as drivers of 4000-5499 lb. vehicles (full-size cars). With or without seat belts, the difference between the safety of heavy and light cars is affected by the difference in available crush space. Crush space is directly correlated with weight for current vehicles. However, there are other techniques to increase crush space available than just making the whole car bigger and heavier. An example of one such technique is shown in Figure 4-7. For todays cars, available crush is related to vehicle weight but if engine deflection technology were applied to light cars then their available crush would actually be superior to conventional heavy cars. Obviously engine deflection technology applied to larger and heavier cars would increase their available crush space to the point where they were again superior to the light weight cars. It is judged however, that the goal of a high degree of occupant safety appears to be achievable with a broad range of car weights.

The expected use of both light and heavy cars in the future will require that more attention be given to the area of "compatibility". For cars with equal barrier test performance the lighter of the two cars will normally be at a disadvantage in a car to car collision with the heavier car due to the greater acceleration it will experience. Technologies are available, however, to make the light and heavier cars compatible by paying attention to force vs. crush relationships for both cars.

It is also reported that for the current average car the following weight increases may be required to meet possible future standards*:

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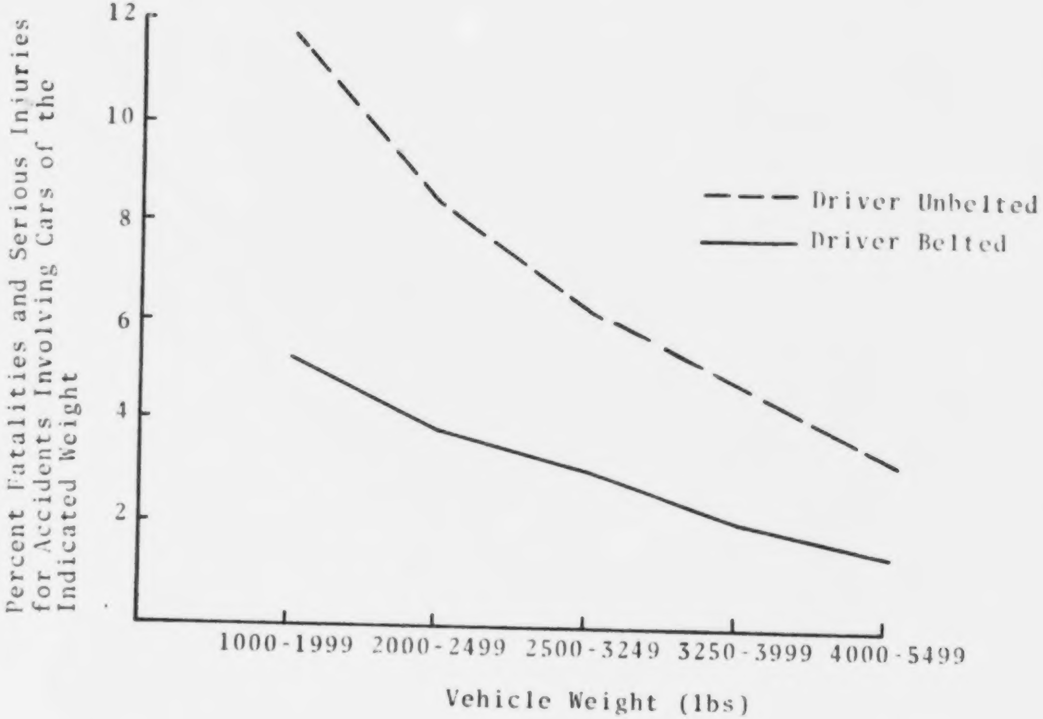
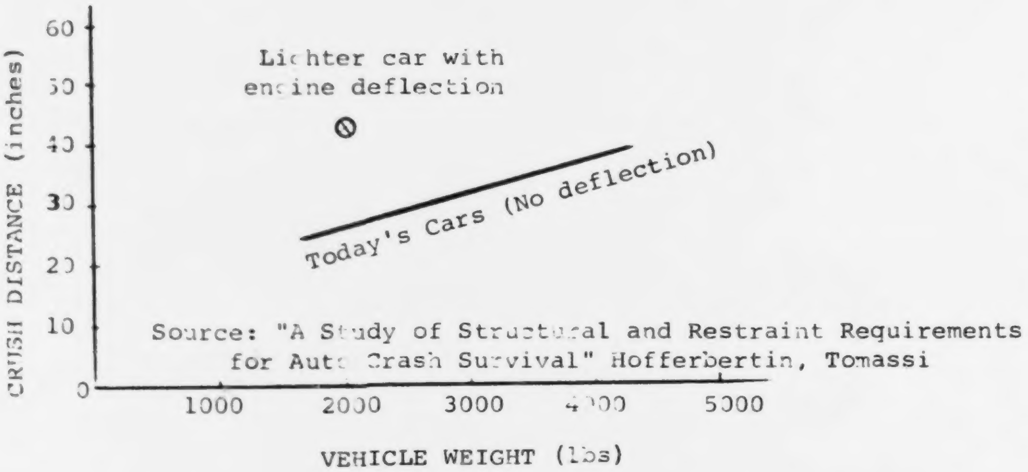
*Source: Safety Panel Report for "Potential for Motor Vehicle Fuel Economy Improvement - Report to the Congress" (DOT/EPA Dec. 1, 1974).



Source: "A Safety Comparison of Compact and Full-Size Automobiles," by Basil Y. Scott, N.Y. State Department of Motor Vehicles, presented at 3rd International Congress on Auto Safety, Vol. I, 15 July 1974 in San Francisco.

Figure 4-6 Percentage Fatal/Serious Injury versus Vehicle Weight



Source: "A Study of Structural and Restraint Requirements for Auto Crash Survival" Hofferbertin, Tomassi

Figure 4-7. Crush Distance Versus Vehicle Weight

Issued Standard Not Yet In Effect

215 (Bumper Corner Requirements) 9/1/75	9 lbs.
105-75 (Hydraulic Brakes) 9/1/75	5-25 lbs.

Possible Future Standards

Before 1980 FMVSS 208 (30 mph)	∿ 55 - 80 lbs.
Part 581 No Damage Bumper	∿ 45 - 100 lbs.
After 1980 FMVSS 208 (45-50 mph)	∿150 - 270 lbs.
Total	∿250 - 450 lbs.

The panel estimates therefore that the typical net weight reductions including safety impact considerations are as indicated in Section 5.1.1.1 and Table 5-8.

4.1.1.4 Manufacturing Lead Time and Cost Impacts -

a. Material Substitution - Reduction in weight through materials substitution involves the use of aluminum and plastics in lieu of steel in the manufacture of hood liners, trunk liners, door frames, engine blocks, heads and manifolds and in plastic fuel tanks, and energy absorbing bumpers and other parts. Light weight aluminum and plastics generally cost more by the pound but are cheaper by volume than steel. Stainless steel is typically 60 cents per pound and Fytel 612 nylon is 130 cents per pound. By volume stainless steel is 16 cents per cubic inch and nylon is 5 cents per cubic inch. Steel weighs approximately seven times as much as the same volume of plastics or rubber. Plastic functional parts enjoy a 50% weight reduction over equivalent parts from steel stampings. However, production costs are higher and the parts do not generally possess the desirable energy absorbing characteristics and resistance to low temperatures of comparable steel parts.

Alcoa has suggested increased use of aluminum and claims a 305 pound weight reduction in a standard size car can be achieved by using aluminum in the hood, trunk, doors (4) and bumper reinforcements. There are production problems associated with the use of aluminum. Welding and scratching, paint adhesion and texture problems increase production and quality control costs. The use of aluminum frames for doors, trunks and hood with a steel skin can alleviate some of these problems. The weight savings under these conditions would be more of the order of 238 lbs. The use of aluminum instead of steel will require 159 lbs of additional aluminum at a cost of $.36 per pound or $58 per car for a standard size car. Tooling equipment facilities and launching costs are estimated at $55 million for the whole fleet adding an additional cost of $3 to $4 per car.

Plastic fuel tanks and energy absorption bumpers would save an additional 60 lbs. and require the substitution of approximately 60 lbs. of plastics for 120 lbs. of steel and cost an additional $8-10 per car. Tooling for all 49 models in current production would require an investment of $149 million dollars and 7-8 years to implement.

Lead time to accomplish material substitution requires 18-24 months for aluminum welding equipment, 8-9 months for new dies and up to 30 months for automatic transfer lines for machining engine blocks, heads and manifolds.

Added to the above is the time required to develop and test new engine components and the design and development time for the new body components which would require up to two years for engine components and a year for body components. These items would be phased into regular production during the model year which coincides most nearly with the development of the new components.

The decision to use either cast iron or aluminum for engine components would be deferred while the development was underway until a cut-off date when a choice would be made. This would probably be 20 months before volume production. A decision to change body panels to aluminum could probably be implemented in two years. Plastic bumper designs would require two years unless the basic structure required change. Otherwise 3-1/2 years would be required.

b. Annual Resources Impacts - The industry as a whole has shown very little interest in materials substitution as a means of weight reduction because of the uncertainty of supply of aluminum and plastics both of which require more energy to produce than steel. Furthermore additional tooling investment, manufacturing costs and consumer price increases would result from these substitutions. Increases in the use of aluminum would result in the order of 120 lbs per car or approximately 6 million tons of aluminum. Plastics and rubber are made from petrochemicals but at the same time save energy because of their light weight. Scarcities of petrochemicals are affecting parts of the plastic industry which adds to the uncertainty. An increase approximately 0.2 million tons of plastics would be required to provide material for plastic bumpers and fuel tanks.

c. Unitized Body Construction - Unitized body construction is used in varying degrees in 40 percent of the new car fleet. All of American Motors cars use a complete frame with a front inner wheel house. Chrysler uses a front subframe with a rear frame and body unit. Ford's compacts and subcompacts employ front and rear subframes except Mustang II which is unitized but utilizes suspension supports. GM's Vega is unitized and its compact cars use front and rear subframes. The basic difference between frame and body construction and the unitized body construction is that with unitized body construction the body and subframe is welded together and in the body and frame construction they are separate assemblies. In addition, the vehicle assembly procedures and tooling requirements for the two types of body construction are totally different.

A change from chassis-frame construction would reduce weight in the neighborhood of 300 lbs. in a standard size car with a corresponding saving in steel of 300 lbs and a potential reduced consumer cost of approximately $120. The assembly plant would have to be completely dismantled, removing the chassis assembly transfer line and the body assembly transfer line and replacing them with a new line for assembly of the unitized vehicle. This will require a complete rearrangement of the plant. The new line including launching cost and facilities changes will cost $40 to $50 million for each increment of production of 250,000 units. The plant will have to be shut down for approximately eight months in order to accomplish the changeover. The additional price to the consumer will be $30 per car for tooling. The net cost to the consumer might be a $90 decrease in price. Normally this kind of a major body change would be done only when converting to a new body design or when building a new facility. These changes can be accomplished within the normal model year production cycle of 4 years for each model. Conversion of all body and frame cars to unitized construction cars would require Ford to invest $0.48 billion dollars and GM to invest $0.80 billion dollars and would require 9-10 years to accomplish.

The resources impact involves a reduction in usage of steel by approximately .9 million tons of steel per year.

4.1.2 Aerodynamic Drag

Aerodynamic drag is only significant at higher speeds and is affected by both frontal area (A_f) and drag coefficient (C_d). The total aero drag is proportional to the product of the vehicle's frontal area and the drag coefficient. Reductions in drag through the frontal area reduction approach were not considered practical by the panel due to the compromises in passenger compartment size and shape that would result. Reducing the crossectional area of the passenger compartment would lead to increases in vehicle length if passenger carrying capacity (vehicle function) is not to be affected. Such a length increase would result in increased weight which would more than offset any economy gains resulting from the drag reduction.

Without affecting crossectional area, reductions in aerodynamic drag can be accomplished by lowering the drag coefficient (C_d). The drag coefficient is related to the vehicle's shape and aerodynamic cleanliness. A smooth, rounded geometry with a lack of projections is highly desireable for obtaining a low C_d.

A.D. Little[3] reported that front end rounding alone would reduce C_d by 12% for most domestic cars. Underbody smoothing, flush mounting door handles and paying attention to rain gutter design and license plate mounting was reported by the same reference to allow further improvements of 10%. Southwest Research Inst.[2] projected up to a 50% improvement might be possible. The panel has however considered a 10% reduction due to frontal rounding to be readily achievable by 1980 with additional improvements of 10% possible beyond 1980 while still maintaining styling flexibility.

A.D. Little[3] showed the effect of a 20% reduction in C_d to result in a 0.9% improvement in urban driving (EPAU) economy and a 2.5% improvement in 50 mph cruise economy. The 50 mph cruise economy change would be close to the change that would be experienced on the Highway Cycle which is a quasi-steady state test with a 48 mph average speed. The composite improvement has been calculated to be 1.7%.

SwRI[2] reported that a 10% drop in C_d would yield a 2% benefit in fuel economy for a 50/50 split of urban driving and steady speed operation. The panel has selected 1.5% as the improvement that can confidently be expected by 1980 without affecting the crossectional area of the vehicle. This magnitude of improvement appears to be achievable with only a 10% improvement in drag coefficient.

Natural Resources Impact

None. Involves only re-styling.

Safety Impact

None.

Emissions Impact

None.

Manufacturing Impact

Vehicle aerodynamic drag reduction in this context involves the changing of the body surfaces by rounding and smoothing. These changes are minor in nature and normally would be done during the model year change. The costs would be absorbed in the model year costs. Tooling would involve new dies. These costs would not result in a price increase.

4.1.3 Rolling Resistance Reduction

Rolling resistance reductions can be made independently of weight reduction by altering tire characteristics. Several parameters affect the rolling resistance characteristics of a tire including principally:

a. Construction techniques
b. Tread depth
c. Inflation pressure
d. Compounds from which tire is manufactured

Probably the most significant change which can be made is in the area of construction technique. According to Huebner[4] the difference in economy due to changes in construction technique can be as great at 13% comparing early belted bias tires to radials. Recent improvements in the belted bias ply tires have reduced the radials advantage to 6%. Compared to conventional non-belted bias ply tires, a good steel-belted radial will show improvements of 3% according to the same reference, 2.5% according to A.D. Little[3] and 4% according to the Southwest Research Institute[2]. The difference between these values and values in the 10% range often used for advertising purposes is that the 2-4% range is correct for a realistic and representative driving cycle that includes stops and starts whereas 10% is only achievable during steady state conditions that do not reflect typical operation. A 2.5% improvement in fuel economy has been chosen for use in this study and improvements related to changes in other tire characteristics have not been assumed. GM indicated that an improvement of this magnitude was "...realistic and conservative."

Changes in tread compound may reduce hysteresis losses somewhat but tread compound must be designed for other important requirements such as, wear, traction and crack resistance which makes optimizing for low hysteresis loss impractical.

Reduced tread depth results in lower rolling resistance but reductions would compromise tire life and result in adverse resource impacts.

Higher inflation pressures reduce rolling resistance at the expense of uneven wear, ride harshness and traction loss with conventional tires. Redesign of the tire for higher inflation pressures, however, could have some potential. The uneven wear and traction problems could be solved, but ride harshness may be more difficult to eliminate.

Additional benefits in the areas of tread life and handling will also be accrued with a conversion to radials. The increase in cost ($100) will be more than offset by the longer life expectancy. Approximately 25% of the 1974 models were equipped with radials, but indications are that a rapid and possibly total conversion to radials is well underway.

4.1.3.1 Lead Time and Production Costs - The reduction of rolling resistance through use of radial tires can be accomplished by all manufacturers. Assuming market demand, the potential exists for 91.5% of domestic production being equipped during the 1975 model year. It is anticipated that usage will increase to 100% by 1979. The current increase in cost to the consumer ranges from $211 for a standard car to $167 and $157 for a compact and subcompact respectively. The 1980 price is anticipated to be lower due to improvement in productivity. Currently most of the wire for producing steel belted radial tires is being purchased abroad. It is anticipated that U.S. tire makers will invest $1 billion for facilities by 1980 to manufacture radial tires. This investment will include modernization of their plants and tooling and will improve their productivity.

4.1.3.2 Safety Impact - Some beneficial safety impacts are likely due to the increased tread life and puncture resistance and superior handling characteristics it offers.

4.1.3.3 Emissions Impact - None.

4.1.3.4 Annual Resources Impact - The use of radial tires will require development of steel wire manufacturing facilities and an increase in the use of steel. Synthetic rubber production for the manufacture of tires should decrease by half by 1980 due to the fact that radial tires give twice the mileage current bias belted tires. The use of nylon polyester, and rayon cords may decrease as they are replaced by steel.

4.1.4 Accessory Power Reduction

4.1.4.1 Technical Description - Major vehicle accessories include items such as the cooling fan and the air-conditioner. In 1974 model cars approximately 70% of the passenger vehicles and 30% of domestic light duty trucks (LDT) have air-conditioners installed.

A significant amount of the engine power is used to drive a set of accessories which are coupled through a flexible Vee belt attached to pulleys on the front end of the engine crankshaft. At present all accessories are driven at a constant ratio of engine speed. It is possible to reduce some accessory requirements by drawing power from the engine only upon demand. In case of the air conditioner nearly all original equipment air conditioners are of the manual control type with the compressor driven at all times while turned on. Exceptions are AMC original equipment air conditioners and aftermarket designs which cycle as a function of a thermostatic control. Several luxury cars have full time automatic temperature control which requires the compressor to operate at all times.

A significant saving could be obtained by incorporating the thermostatically controlled cyclic air conditioner in all vehicles.

Alternatives include constant speed drives or a two-speed accessory drive for both the air conditioner and the other accessories. Since a cyclic air conditioner is a proven device (as compared to the constant speed or two-speed drives) it could be implemented in the short term.

The fuel economy penalty due to the operation of air conditioning depends on many variables including driving cycle, ambient temperature and degree of temperature control desired. Tests and analyses performed by the Southwest Research Institute[2] give the following fuel economy penalties due to air conditioning.

Driving Mode	Percent Decrease in MPG
EPA Urban Cycle (EPAU)	4.8
Road Load	8.5
Average	6.1

Considering a market penetration of 70%, six months usage during the year and a duty cycle of one-third, the fuel economy improvement would be estimated to be 1.4% due to the use of the thermostatically controlled unit. A.D. Little[3] reports a 3% fuel economy saving during operation with the air conditioner on a one-third duty cycle.

4.1.4.2 Manufacturing Lead Time - American Motors and the aftermarket offer a automatic declutching accessory drive. Ford and GM could incorporate such a device in two years. Cost to the consumer would be approximately $10. Tooling already exists to manufacture such devices. An additional $2 million should provide the additional capacity required.

4.1.4.3 Natural Resource Impact - None.

4.1.4.4 Safety Impact - None.

4.1.4.5 Emissions Impact - None.

4.2 TRANSMISSION IMPROVEMENTS

4.2.1 Improved Automatic Transmission

Improvements to the automatic transmission used currently that would have a beneficial effect on fuel economy were grouped into two general classes; addition of an extra gear or gears to provide better load matching, and reduction or elimination of torque converter slip.

4.2.1.1 Addition of an Extra Gear of Gears - The number of gears in a transmission, their gear ratios and the axle ratio of the vehicle are all chosen to attempt to balance vehicle performance and economy. The basic route toward improved fuel economy via this method is slower engine speed for a given load. One way to do this would be to change from current axle ratios to lower numerical value axle ratios. This was not considered too practical since the axle ratio in most of today's vehicles has already been lowered and further reductions would result in losses in performance and potential pinion gear manufacturing and size problems. Making the top "high" gear like an overdrive ratio is another approach and would eliminate the pinion gear problem, but the performance loss would remain. An approach considered practical is the addition of an extra gear in the transmission (from three speeds to four speeds in most cases). The fourth gear would be used as an overdrive and the other three gear ratios could be re-optimized for improved economy with no performance loss.

4.2.1.2 Elimination of Torque Converter Slip - Current torque converters used in conventional automatic transmissions slip even under steady state conditions. The approach toward eliminating this loss in efficient power transfer is to "lock-up" the torque converter under some conditions, typically using some form of clutch, to prevent the slip losses that occur. This approach would theoretically be used on all gears of the transmission, but to do so on all gears could prevent the torque converter from doing its job, which is to multiply torque. For this study the following two cases were considered:

a. Lock-up in high gear only
b. Lock-up in all but the lowest (first) gear

The concensus of industry opinion appeared to be that the first approach, the lock-up in high gear, was more practical. The driveability, performance, and emissions were said to be unknown or possibly worse with the second approach.

4.2.1.3 Transmission Concepts Considered - As improvements to the conventional automatic transmission, two approaches were considered. The first approach is the addition of an extra gear and lock-up in high gear only. The second approach is the addition of an extra gear and lock-up in all but the lowest (first) gear. Allison Division of GM currently sells an example of the latter concept for trucks. Lock-up was added to both concepts since it is possible that just the addition of an extra gear to a conventional automatic transmission might provide a deleterious effect on economy because at the lower driveshaft speed, the extra torque for the same power might be obtained by having the torque converter slip more.

The fuel economy improvements for the transmission types considered are listed below.

	Additional Gear Lock-up in High	Additional Gear Lock-up in all But Low
Large	+8.7%	+12%
Mid-Size	+8.7%	+12%
Small	+8.7%	+12%

4.2.1.4 Lead Time and Cost - The lead time for the first approach depends to some extent on how the extra gear and lock-up are implemented. For example, an extra gear could be included by adding a two-speed element in the driveline between the transmission and the differential. This is possibly achievable sooner than putting the extra gear in the transmission, but is more costly and does not perform the lock-up function. Therefore, it was not considered, even though it is an interim improvement and will be used by at least one manufacturer for 1975. It was considered more likely that modification of the current transmission would be the chosen route, enlarging the housing, if necessary, to accept the extra gear, clutches and shift logic.

A report by the Aerospace Corp[7] gives the time from receipt of orders by the transmission suppliers to vehicle production as approximately 19.5 months, with compression possible to 17.5 months, for a new design transmission. This is not the whole story however, since time for development of the new design must be added to the above values.

This development time for transmissions varies from about 24 months for a less than major design change, all the way up to 72 months. For the purposes of this study a development time of 30 months has been estimated for the addition of an extra gear with lock-up in high gear and a development time of 42 months for the development of the extra gear with lock-up in all but low (first) gear. This additional development time requirement is necessary because of the myriad of combinations of shift logic, gear ratios, axle ratios, and control techniques that must be investigated to fully optimize the package for smoothness, economy, performance and emissions. The lead time for the two modifications to existing automatic transmissions is summarized below.

TABLE 4-9 AUTOMATIC TRANSMISSION LEAD TIME*

Concept	Additional Gear Lock-up in High	Additional Gear Lock-up on all But Low
Development	30 months	42 months
Production	19.5 months	19.5 months
Total Lead Time	4+ years	5+ years

*Source: Aerospace Corp.[7]

It is not known how far along the manufacturers are in the development of such transmissions. Development work appears to be further along with the additional gear plus lock-up in high concept.

The additional customer cost and investment cost for one of the two concepts is listed below:

	First Cost	Investment	% Usage by 1980
Large	$16	$18.5M/line	100%
Mid-size	$14	$18.5M/line	100%
Small	$12	$18.5M/line	50%

4.2.1.5 Other Modifications to Conventional Automatic Transmission - In addition to the options of a four speed transmission with lock-up, the following options are also available to industry:

a. Lower slip converter

b. Three speed with lock-up in third

c. Three speed with lock-up in second and third

d. Wide range 3-speed (with reduced axle ratio)

e. Wide range 3-speed (with reduced axle ration) with lock-up in third.

These options require shorter implementation times and smaller investiments than the four speed transmissions. The potential fuel economy benefits for these options are:

a. Lower slip converter (DOT simulation)............ 1.9%
b. Three speed with lock-up in 3rd (DOT simulation).. 3.4%
c. Three speed with lock-up in 2nd and 3rd (")....... 4.7%
d. Wide range 3-speed (estimated).................. 4%
e. Wide range 3-speed with lock-up in 3rd (estimated) 5%

4.2.1.6 Natural Resource Impact - The impact on natural resources comes primarily from the additional material (gear and clutches) used in the modified transmission. Some slight increase in the requirement for ferrous materials may result, if the transmission weight increases, as it is likely to do, by approximately

5%. This additional weight may make the use of alloy materials more attractive, for example, making the housing from aluminum, rather than cast iron. Such changes across the board would reduce the cast iron requirement and increase the aluminum requirement for transmissions.

4.2.1.7 Safety Impact - If safe passing power is maintained, and there is no reason to believe that it cannot be maintained or improved, negative safety impacts do not appear to be apparent with either transmission concept. Some flexibility in safety design may be possible, if new housings are required and the designs are incorporated into engine and transmission mounting systems designed to deflect the engine under the vehicle in a frontal crash.

4.2.1.8 Emissions Impact - Today's automatic transmissions are a vital part of the engine/transmission package that must be optimized for emissions. Shift logic, shift control and operating characteristics all impact the engine calibrations necessary to meet the standards. The transmission is even used as a feedback element in the control of spark timing in some cases, the transmission controlled spark (TCS) systems being one example.

Two possible competing mechanisms influence the likely emission performance of the transmission concepts. First, both transmission types should tend to reduce exhaust volume per mile, which would help emission performance. However, both transmission concepts tend to make the engine operate under higher load conditions, which would tend to alter the engine's emission performance.

Both transmission concepts will require development and optimization to ensure that the engine/transmission package works as an integrated system. For the purposes of this study no emission advantage or disadvantage was assigned to either concept. However, the additional gear plus lock-up in all but low concept will require more development time since the number of variables to optimize is greater and this concept may affect the emissions more, since the lock-up operation occurs a greater fraction of time on the emissions test.

4.2.2 Manual Transmissions

4.2.2.1 Discussion - Manual transmissions were not given major emphasis in this study as a possible route toward improved fuel economy for the large and mid-size automobiles for the following reasons: a) many people do not know how to drive manual transmission equipped vehicles. The installation rate of automatic transmissions on new domestic cars sold in the U.S. has been above 90% for several years now, thus making the major portion of the automobiles on the road automatic transmission equipped. This also implies that the great majority of new drivers have learned to drive automatic transmission equipped vehicles, therefore, it is not realistic to postulate a major shift toward vehicles with manual transmissions in 1980 which most people will not know how to drive; b) while it may be true that manual transmissions are more efficient power transmission devices, use of manual transmissions does not guarantee fuel economy benefits over automatic transmissions, because the manual transmission must be operated properly to achieve the benefit. Manual transmissions can be operated so that poorer, not better, fuel economy results. Expert drivers can show gains, but considering that most people do not know even how to use a manual transmission, it does not appear realistic to assume that they would use it properly; c) the improved automatic transmissions considered here will significantly reduce the current difference between an automatic transmission and a properly operated manual transmission.

Some improvements to manual transmissions, however, have been included in this study. Primarily these improvements are the addition of an extra gear to the manual transmissions used on small vehicles. For most of the vehicles affected, this means a change from a four-speed to a five-speed transmission, with fifth being an overdrive ratio. For the small car class this improvement is 4% in fuel economy.

4.2.2.2 Lead Time and Cost - The lead time for the addition of an extra gear is shorter than the first case discussed in the automatic transmission case, because the design and development time should be shorter. The lead time is summarized below.

Addition of an Extra Gear[7]

Development	24 months
Production	19.5 months
Total Lead Time	43.5 months

This lead time is probably a bit conservative, since some manufacturers already offer five-speed transmissions as an option.

The cost impacts are listed below for the small car class only.

Manual Transmission Cost and Investment

1st Cost Increment	Investment Millions	% Usage by 1980
$26	$31M/line	50

4.2.2.3 Natural Resources Impact - Slight increases in the use of ferrous materials used in manual transmissions for small vehicles can be expected.

4.2.2.4 Safety Impacts - As with the case of the improved automatic transmissions, no adverse safety impacts are foreseen.

4.2.2.5 Emissions Impact - The addition of an extra gear will have relatively little impact on the emission performance. This is not to say that manual transmission-equipped vehicles in general have an easy time meeting emission standards, it means that the addition of an extra gear will not make the job any tougher or easier.

4.2.3 Continuously Variable Transmissions

4.2.3.1 Discussion - Current transmissions have multiple speeds in them to match the engine speed to the road speed. The number of gears chosen and their respective ratios are compromises among cost, performance, fuel economy and emissions, as examples of constraints. Generally speaking, transmissions with larger numbers of gears permit better optimization and load matching between the engine and the vehicle power requirements.

Continuously variable transmissions (CVT's) can be thought of as transmissions with a very large number of gears. Ideally, CVT's can provide a continous variation of output speed to input speed (N_o/N_i) over a wide range of N_o/N_i.

Theoretically, the degree of flexibility offered by CVT's would almost allow the engine speed to be independent of the vehicle speed, and the choice of engine operation could be optimized toward a desired goal, improved fuel economy for example. Although a great variety of CVT concepts have been proposed over the years, this report has considered only the two types that appear to be currently the most developed for use in the power ranges considered necessary for the large and mid-size vehicles. These two types are the traction drive and the hydromechanical.

Traction drive depends on rolling contact to transmit torque. The speed ratio variation is obtained by changing the radius ratio over which the driving and driven elements of the transmission are acting.

Major problems with this type of transmission are the need for specialized lubricating oils, wear, possibly cost, and the choice of the optimum loading between the rolling contact members themselves. No traction drives are currently in production.

Hydromechanical transmissions are a combination of two types of drives; hydraulic and mechanical. The two types of drives are combined in such a way that most of the power is transmitted through the efficient mechanical portion, while the speed ratio variation is obtained through use of a hydraulic pump/motor.

Problems with this type of transmission are size and weight, noise and cost. One example of this type of transmission is currently on the market for heavy duty truck applications. Three problems exist with both CVT types: engine load factor, controls, and acceptance.

For the CVT to have a major beneficial effect on fuel economy, the engine operating condition must be altered significantly. To improve fuel economy the engine must be operated at higher load than currently is the case. This means that the engine load factor over its life is increased, especially at low vehicle speeds and engine torques where current engines are not too efficient. It is expected that re-design of the lubrication system, cooling system, bearings, and possibly crankshafts would be necessary for successful adaptation of a CVT. Use of components currently applied to heavy duty gasoline engines, however, may prove to be adequate. The second common problem is the control system. If the engine speed can be divorced from the vehicle speed, a control system is necessary that provides the necessary power as required by the driver. This will be more complicated than today's throttle, since the engine speed and load, and the transmission speed ratio have to be programmed in a stable way to provide safe, smooth predictable response.

The third common problem is the unknown acceptance by the user of engine noise of a much different nature than is the case today. This is hard to quantify, but it would appear unusual, at least, to have the engine sound changing with no input from the driver.

Possibly because of the above problems the automobile manufacturers do not have major programs in CVT's targeted toward automobile use for the near future. The lack of effort could be considered another problem since the CVT concept offers substantial theoretical fuel economy benefits, which could be in excess of a 20% improvement.

4.2.3.2 Lead Time and Cost - Because of the less refined state of development of CVT's compared to conventional automatic transmissions, the development time is expected to be longer. Also because the components are substantially different the tooling time is estimated to be longer as shown below:

CVT Lead Time Estimates[7]

Development	48 to 60 months
Production	24 to 36 months
Total Lead Time	72 to 96 months (6 to 8 years)

The total lead time estimates for the CVT put it somewhat outside the primary scope of this study.

The cost increment and the manufacturing investment for CVT's are not well known at this time, the following table gives ranges considered reasonable.

TABLE 4-10 CVT COST INCREMENTS AND INVESTMENT

Vehicle Type	1st Cost Increment*	Investment Millions**	% Usage by 1980
Large	$32	100	Small
Mid-Size	32	100	Small
Small	32	100	Small

4.2.3.3 Natural Resource Impact - The impact of CVT's is estimated to be a slight increase in the demand for ferrous materials, if, in fact, they are heavier than conventional transmissions.

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* Over an automatic transmission
** Millions per line

4.2.3.4 Safety Impact - The problem of developing an adequate control system is such a major problem because adequately safe vehicle operation must result. This is not a negative safety impact however, but an extra constraint on the control system design. As long as the vehicle behaves in a manner like conventional vehicles for nominally the same driver inputs, no adverse safety impact is foreseen. However, maintaining the same response may be difficult to do in the light of optimization for fuel economy, engine braking performance being just one example.

4.2.3.5 Emissions Impact - Since the engine's operation is substantially changed, a difference in emission performance is likely to result. However, the direction, much less the magnitude, is not possible to quantify since there is virtually no emission data available on CVT-equipped vehicles compared to a baseline case. The development program necessary to bring a CVT to production will have to involve re-optimization of any emission control system.

4.3 ENGINE IMPROVEMENTS

4.3.1 Discussion

The capability for improvements in engine efficiency is a function of the efficiency of the baseline engines. Since currently available engines are not equally efficient, the use of an engine with a specific efficiency in the future will result in a different percentage improvement for different vehicles.

The differences in efficiency of the engines currently used to power passenger cars are due to many factors including:

a. Differences in spark timing
b. Differences in carburetion
c. Differences in exhaust gas recirculation system
d. Differences in friction
e. Differences in pumping losses

With the exception of "differences in EGR system" these same differences existed for uncontrolled engines.

Differences in spark timing in uncontrolled engines resulted from differences in combustion chamber geometry and compression ratio. For a given octane value of the fuel, spark timing, chamber geometry and compression ratio must be optimized for best economy. Different engine designs resulted in some differences in spark timing and efficiency both.

For emission controlled engines differences in spark timing cause a much greater difference between engines because the range of spark timing calibrations used is much wider. The range is wider because spark is no longer just set for optimum economy. Many manufacturers are now using alterations in spark timing to reduce emissions (primarily hydrocarbons).

The reduced expansion of the burned gases that is caused by retarded spark elevates the temperature of the exhaust gas and promotes post cylinder oxidation reactions which consume a portion of the hydrocarbons which were not combusted in the cylinder. The retarded timing also results in reduced exposure of the charge to high temperatures as the rate of expansion during the combustion is greater with retarded timing. This reduces NOx emissions to some extent since NOx is formed more readily at high temperatures.

If one manufacturer has relied more heavily on spark retard to meet emission standards than another manufacturer then the manufacturer using the greater amount of spark retard can make greater improvements than the manufacturer who used less spark retard. This situation, in fact, exists today as manufacturers who were more interested in achieving good fuel economy have relied on alternate and more efficient techniques to reduce emissions (e.g., air injection, improved fuel metering, improved combustion chamber design, etc.). Spark retard, however, has been a popular approach because the cost of retard is zero to the manufacturer or very small depending on the way it is accomplished.

A 25° spark retard can cut HC emissions by 60% but a fuel economy loss of 17% can result (SAE paper No. 740104).[8]

The carburetor calibration used on uncontrolled vehicles depended on the performance criteria the manufacturer considered the more important. Trade-offs were made between fuel economy and driveability and usually driveability was given primary consideration. The carburetor calibration that results in best economy depends primarily on:

a. Capability of the carburetor to atomize the fuel

b. Capability of the intake manifold to distribute the fuel/air mixture uniformly

c. Ability of the ignition system to ignite the mixture

For the typical uncontrolled car the best economy was achieved at air-fuel ratios of approximately 16.5:1, but most cars had somewhat richer calibrations than this to improve driveability.

To meet emission standards many manufacturers have revised their carburetor calibrations to something closer to the best economy air-fuel ratio. HC and CO emissions tend to be lower at the best economy air-fuel ratio than at richer ratios since higher oxygen concentrations in the cylinder and the exhaust which occur with lean mixtures promote the oxidation of HC and CO into carbon dioxide and water. A 40% reduction in HC and greater than 50% reduction in CO can be achieved by leaning the carburetion from 14:1 to 16.5:1 (SAE 740104). A 7-10% increase in economy could accompany that change. An adverse effect of leaner calibration can be a negative impact of driveability. Manufacturers who did not improve mixture atomization, distribution or ignition sufficiently to compensate for the negative effect on driveability were beset with customer complaints.

An alternate carburetor calibration approach that has been used by some manufacturers is to leave the air-fuel ratio richer than the best economy air-fuel ratio and to add air injection. The carburetor calibration approach which a manufacturer is currently using will, therefore, affect the percentage improvement he can realize with the use of any particular improved system.

4.3.1.1 EGR - Exhaust gas recirculation (EGR) has been commonly thought of as one of the principal causes for the loss in fuel economy that has been experienced by many late model cars which have used EGR to reduce peak flame temperature and thereby curb NOx emissions. In most cases EGR has caused fuel penalties because the most common EGR systems adversely affect combustion during part throttle operation necessitating mixture enrichment in some cases to restore good combustion. More sophisticated EGR systems, commonly referred to as "proportional EGR" (PEGR), do not cause this penalty but PEGR is currently a rarity.

Some of the lighter weight vehicles have avoided the use of EGR because their uncontrolled NOx emission levels were sufficiently low. While the use of more sophisticated EGR technology may result in economy gains for many manufacturers those that do not need so much NOx control have no losses to make up and therefore will be unable to gain as much.

4.3.1.2 Friction and Pumping Losses - Not only must a vehicle engine provide the power to move the vehicle and run the engine accessories, it must also keep itself running. The amount of fuel required to do that depends on the amount of friction and pumping losses the engine experiences. Generally these losses are in direct proportion to the displacement of the engine for a given weight of vehicle. Vehicles with large engines can therefore make significant gains in fuel economy by using smaller displacement engines. The engine size reduction approach is however not practical for vehicles which currently have modest power to weight ratios for two reasons:

a. Further engine size reductions could reduce the performance of the vehicle to the point where passing maneuvers could not be completed as safely.

b. Further engine size reductions could result in increased use of the carburetor's power circuit during urban driving conditions. This would adversely affect both fuel economy and exhaust emissions performance.

The composite changes which have been made to engines to meet current emission standards have resulted in efficiency losses for the engines in heavier vehicles, but the engines in the lighter vehicles have been essentially unaffected. This is shown graphically in Figures 4-8 and 4-9.

Figure 4-8 shows the urban cycle fuel economy of 1974 and uncontrolled cars (1957-1967) as a function of their weight. For both groups of cars it can be seen that the lighter vehicles have better fuel economy than the heavier vehicles. Notice however that the difference in economy between lighter and heavier cars is greater for the 1974 vehicles than for the uncontrolled vehicles.

The comparison between the 1974 models and uncontrolled cars is perhaps better shown in Figure 4-9. 1974 vehicles in weight class 3500 pounds and lighter have slightly better economy than their uncontrolled counterparts but 1974 vehicles in weight class 4000 pounds and heavier have experienced significant losses.

The disparity between the effect emission standards have had on light and heavy vehicles is apparently due to the fact that light-weight vehicles have required less emission control than heavier vehicles and control measures that adversely effect engine efficiency have not been used as much as they have on heavier cars.

Briefly summarized, the possibilities for significant economy gains due to engine improvement are the greatest for those models that have experienced significant economy losses. For models that are currently equipped with efficient engines, gains will be more difficult.

4.3.1.3 Potential for Improvement - Figure 4-8 should not be considered as representative of the optimum fuel economy performance of conventional engines just because it is based on uncontrolled cars. Uncontrolled cars were not always optimized for fuel economy. First cost and driveability constraints often were considered more important. Many uncontrolled cars were calibrated

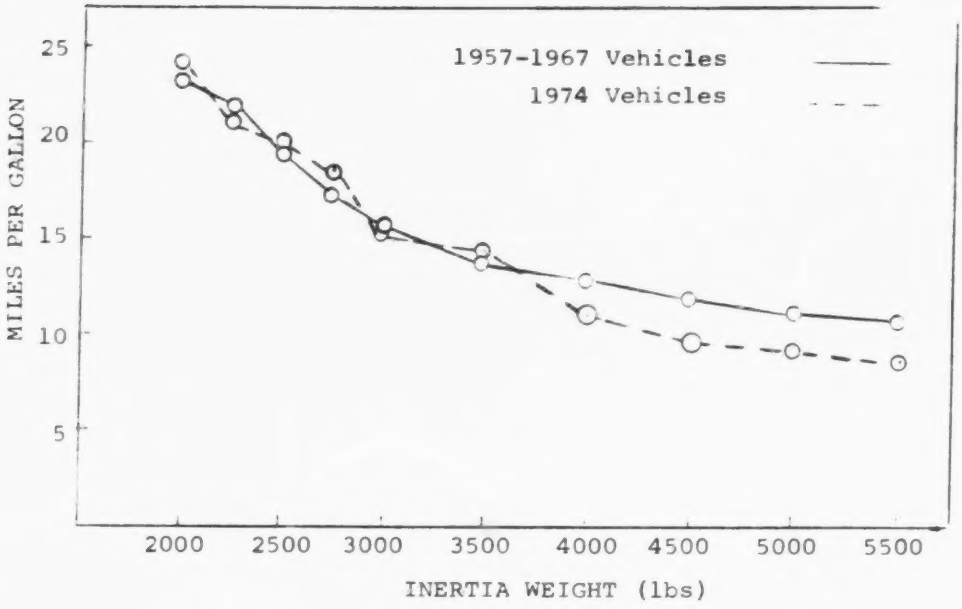


Figure 4-8 Fuel Economy versus Vehicle Weight

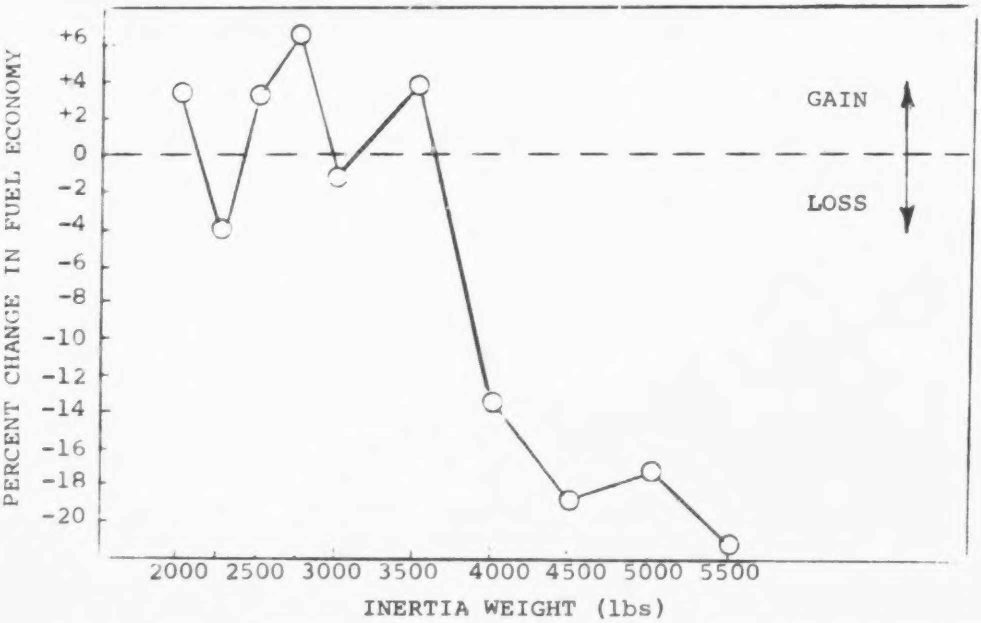


Figure 4-9 Percent Change in Fuel Economy Between Uncontrolled and 1974 Models versus Inertia Weight

with richer air-fuel ratios than necessary for best economy and some even lacked vacuum spark advance for cost reasons.

In order to determine what a more optimum fuel economy vs. inertia weight graph would look like an extensive review of the model year 1975 certification data was made. For each inertia weight class the economy of the better certification cars was averaged for each inertia weight class and then plotted in Figure 4-10. Data from seventy-six different cars made by thirteen different manufacturers was used to construct Figure 4-10. Cars with low power to weight ratios were excluded from the analysis. Small cars were only used if their net horsepower (HP) divided by their inertia weight (IW) class was .025 or greater. Large and mid-size cars were only included if their HP/IW was .030 or greater. This meant that many popular models such as the Volkswagon Beetle, AMC Matador 6-cylinder, Ford Maverick 6-cylinder, Dodge Dart 6-cylinder and many others were not considered even though their fuel economy may have been superior to the economy of the cars that were selected.

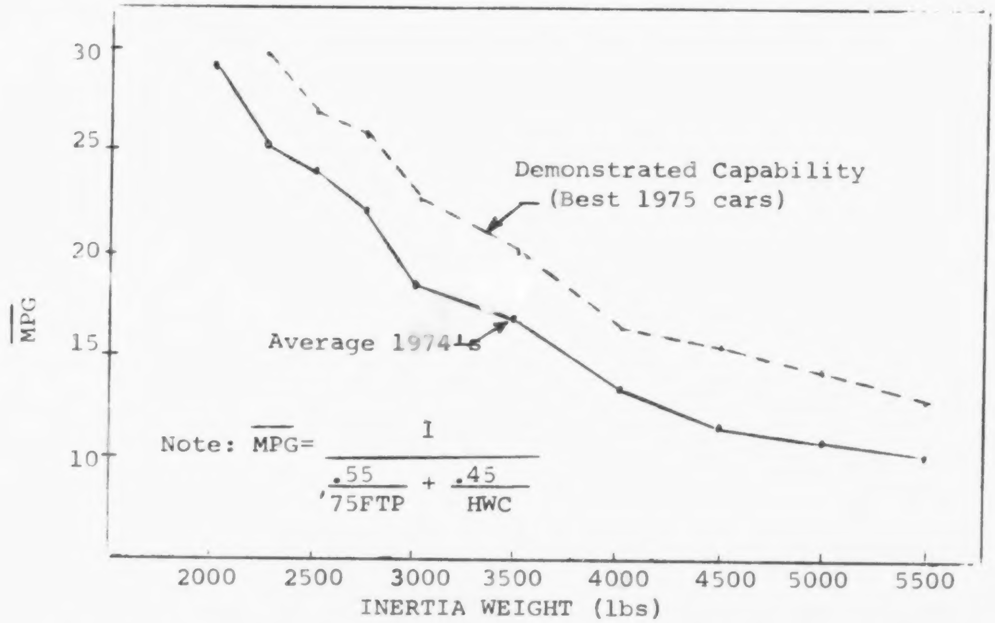


Figure 4-10 Fuel Economy versus Weight for "Optimized Vehicles" Compared to 1974 Average

The above selection criteria may have caused the mean horsepower to weight ratio of the best model year 1975 cars to be slightly lower than the mean power to weight ratio of the model year 1974 cars. Power to weight ratios for the model year 1973 cars, which were more readily available than the 1974 cars were 4.7% higher than the mean power to weight values for the best 1975 cars used in the analysis. It is expected that the difference in power to weight ratio between the 1974 and 1975 models would be even less than 4.7%, because weight increases were realized with many 1974 models without engine changes.

Table 4-11 shows how the more efficient 1975 models compare with the 1974 models. The possible improvements were estimated from the data in Table 4-11. Allowances were made for possible changes in axle ratio and power to weight ratio. The analysis resulted in the values shown in Table 4-12. It should be pointed out that these values apply to the average 1974 vehicle, not every vehicle. Some 1974 vehicles, at least in the lighter weight classes, were already as good as the best 1975's.

The values listed in Table 4-12 are considered to be somewhat conservative since they are based on the assumption that the best 1975 models are representative of the most that can be done with conventional engines. While some manufacturers have demonstrated substantial improvements for 1975, it is likely that further gains can be made, for example GM stated that a 5% improvement over their own 1975 systems could be made with combustion chamber modifications.

4.3.2 Conventional Gasoline Engines

Several conventional engine systems were considered before the panel decided on three configurations which appeared to have the greatest potential for use in the future. The systems considered included:

a. Lean Thermal Reactor (LTR)
b. Rich Thermal Reactor (RTR)
c. 3-way Catalyst (3-way)

TABLE 4-11 1974 ECONOMY VERSUS OPTIMUM ECONOMY

IW Class	$\overline{\text{MPG}}$ 1974	$\overline{\text{MPG}}$ Best '75's	% Change '75 vs. '74
2000	29.1	---	---
2250	25.3	29.7	+17
2500	24.0	27.0	+13
2750	22.2	25.9	+17
3000	18.4	22.9	+25
3500	16.9	20.1	+19
4000	13.2	16.3	+23
4500	11.5	15.4	+34
5000	10.9	14.1	+29
5500	10.1	12.8	+27

Note: $\overline{\text{mpg}} = \dfrac{1}{\dfrac{.55}{\text{'75 FTP}} + \dfrac{.45}{\text{HWC}}}$

TABLE 4-12 POSSIBLE ECONOMY IMPROVEMENTS WITH ENGINE OPTIMIZATION

Vehicle Class	Improvement Possible
Small	15%
Mid-size	20%
Large	25%

d. RTR-NOx Catalyst-RTR (Questor)
e. Oxidation Catalyst and EGR
f. Lean burn engine with oxidation catalyst
g. Dual Catalyst

Of all of the candidate systems considered, letters e, f and g above were selected for more detailed analysis.

System a (LTR) was not considered because of the difficulty it has in controlling HC and CO emissions to the .41 and 3.4 levels and the fact that it does not appear to have any significant fuel economy benefits over systems which can achieve .41 and 3.4 gpm HC and CO respectively. Reference (73-28)[9] showed that the LTR system had fuel economy that was essentially the same as an uncontrolled car while HC emissions were about .8 gpm and CO emissions about 5.7 gpm.

System b (RTR) was not selected for detailed analysis because of its difficulty in achieving the 3.4 gpm CO emission level and because of the fact that the fuel economy performance of this system is generally inferior to the systems selected for detailed analysis. References (71-3)[10], (72-26)[11], (72-21)[12] and (72-3)[13] showed the rich thermal reactor approach to result in low HC and NO_x emissions but CO is nearly twice that required to certify at 3.4 gpm on the best systems. Fuel economy losses of 20-30% compared to uncontrolled cars are not uncommon.

System c, the 3-way catalyst system, was not considered further because the emission durability performance has been generally poorer than other catalyst systems while the fuel economy performance is no better. It is believed that poor emission performance is the result of attempting to achieve high catalyst efficiency with an exhaust composition which is not optimum for the conversion of any one pollutant, but rather a compromise to obtain catalytic conversion of all three exhaust pollutants (HC, CO, and NO_x) in one catalyst. Nevertheless, further development of this system may ultimately give results as good as or better than those of the dual catalyst.

System d, the Questor system, was not selected because of the requirement for rich mixture operation, which is not conducive to good fuel economy. It appears, however, from published data (73-5)[14], (73-9)[15], (74-9)[16], that the Questor system has the capability of achieving the .41 HC, 3.4 CO, 0.4 NOx emission levels.

Systems e, f and g are discussed in more detail below.

4.3.2.1 Oxidation Catalyst and EGR - The oxidation catalyst and EGR system is the basic control approach scheduled for most 1975 model cars. At the writing of this report, certification of 1975 model year vehicles using this basic system is just being completed and the system is showing itself to be a reliable and effective one. The basic components used are shown in Figure 4-11.

The key component is of course the catalytic converter itself. There are two basic types of catalysts—monoliths and pellets. Despite their difference in physical appearance, they do the same thing, i.e., promote the oxidation of HC and CO into carbon dioxide (CO_2) and water vapor (H_2O). This conversion is accomplished with extremely high efficiency (80%) once the catalyst has reached its "light off" temperature (typically 400-600°). Currently the catalyst is only elevated to the light off temperature by the engine exhaust gas passing through it. Prior to the achievement of light off the exhaust that passes through the catalyst is not "cleaned up" by the catalyst so rapid catalyst warm-up is of prime importance.

Many materials cause a catalytic conversion of HC and CO but the two principal ones are platinum (Pt) and palladium (Pd). These are both "noble" metals and very expensive ($150/ounce for Pt) but since only small quantities (.05 ounces) are used for each car the cost of the noble metal itself is modest. Research continues to find "base" metal compounds which can be used to replace the noble metals for cost savings. This work may prove fruitful as several base metal catalysts have shown good performance.

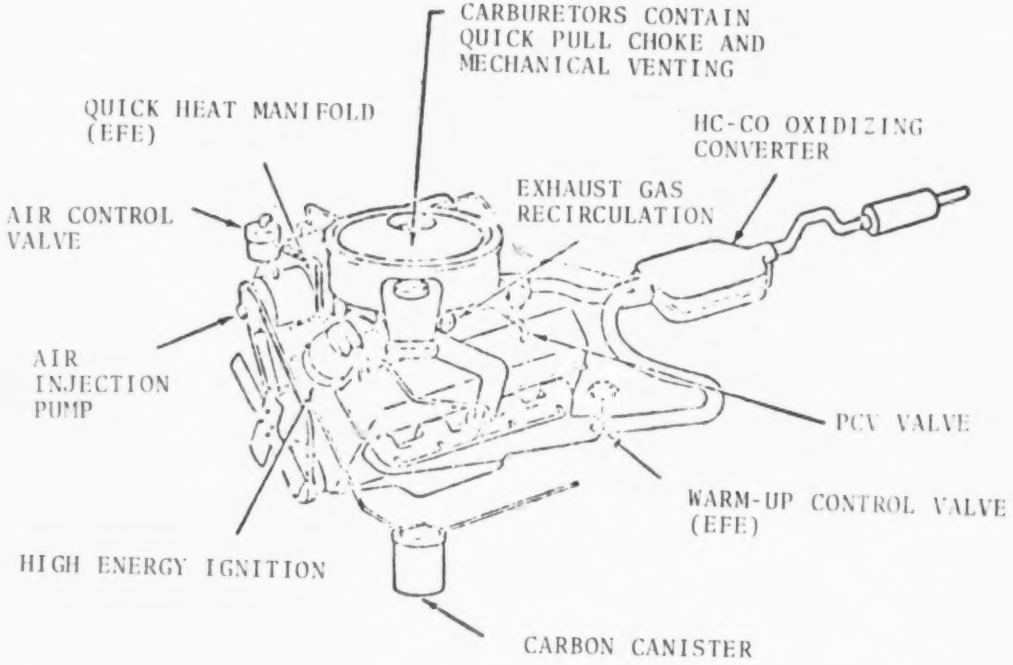

CARBURETORS CONTAIN QUICK PULL CHOKE AND MECHANICAL VENTING
QUICK HEAT MANIFOLD (EFE)
HC-CO OXIDIZING CONVERTER
EXHAUST GAS RECIRCULATION
AIR CONTROL VALVE
AIR INJECTION PUMP
PCV VALVE
WARM-UP CONTROL VALVE (EFE)
HIGH ENERGY IGNITION
CARBON CANISTER

Figure 4-11 Oxidation Catalyst and EGR System (Typical 1975 System)

Air injection pumps are often found on catalyst systems. If the engine calibration is rich the air pump is required in order that oxygen is available for the oxidation of HC and CO over the catalyst bed. When the carburetor calibration is leaner than stoichiometric, oxygen is available without an air pump. However, lower emissions are usually achieved when an air pump is added to increase the oxygen concentration.

Exhaust gas recirculation is used on most 1975 models to control NOx emissions. The exhaust gas which is mixed with the fresh intake charge reduces NOx by absorbing heat from the combustion and reducing peak combustion temperatures. This in itself would tend to degrade engine efficiency but the use of EGR results in a reduction in pumping losses and an improvement in the specific heat ratio of the intake charge which tends to improve economy. EGR is capable of reducing NOx by 80%. Reductions of this magnitude are not required for 1975 models, however, and EGR rate and/or system type are reoptimized to avoid any of the negative aspects of calibrating for 80% reductions (e.g., higher HC, increased system costs).

Quick warm up or "quick heat" systems are used on some 1975 models. These systems consist of a valve located in the exhaust system (usually in the exhaust pipe on one side of a V-8 engine) and an intake manifold with passages cast in it for the transfer of exhuast gas from one part of the exhaust system to another. During cold start up the valve is closed and a portion of the engines' exhaust is directed through the intake manifold to the other portion of the exhaust system. The hot exhaust gas causes the intake system to be warmed up rapidly thereby reducing the carburetor enrichment (choking) normally required for cold starts. The result is improved driveability and significant reductions in HC and CO emissions. This type of system has nothing to do with the catalyst and could have been used on 1974 and earlier models.

The use of the catalyst system on the 1975 models is resulting in substantial improvements in economy for some manufacturers. The principal advantage of the catalyst is that it provides emission control with no adverse effect on fuel economy. This allows avoidance of control techniques which tend to adversely affect economy. The elimination of spark retard on many 1975 models is responsible for some of the gains being recorded. General Motors has developed one of the most effective oxidation catalyst systems which may result in improvements for 1975 close to the 20% target of this study according to GM. There is nothing magical, however, about the catalyst system. The use of the catalyst is just one of many techniques which can and are being used to improve the economy of many 1975 models. One manufacturer has achieved a 16% improvement on their mid-size model without the use of a catalyst. Other manufacturers are showing fuel economy losses for 1975. It is not so much the general type of system chosen that is responsible for gains or losses on the 1975 cars but rather the degree of importance the manufacturer placed on fuel economy in the design and development stage and in the final system selection for production.

In 1974 there were many manufacturers who considered the achievement of good fuel economy to be more important than did other manufacturers. This contributed to the wide spread of fuel economy values shown in the EPA "Buyers Guide" for 1974. For 1975, more manufacturers are showing increased concern for achieving good economy. More manufacturers are incurring first cost penalities (although slight) in order to produce a vehicle that has better economy.

While not all manufacturers who are demonstrating economy gains for 1975 are relying on the catalyst system it is undoubtedly one of the best systems available for fuel economy optimization of emission controlled engines. For this reason it has been selected for more detailed review by the technology panel.

Based on an analysis of available data and technical reports the panel has concluded that the oxidation catalyst system which may best provide the ability to optimize fuel for economy while meeting stringent emission standards would use the following hardware:

a. Large Volume, High Efficiency Catalyst
b. High Energy Ignition System (HEI)
c. Proportional EGR (PEGR)
d. Improved Quick Heat Intake System (QHI)
e. Modulated Air Injection System (MAI)
f. Cold Start Emission Reduction System

The first four items are included on many 1975 models.

a. Catalysts - Currently available catalysts, such as the GM260, may prove to be acceptable but further improvements are possible through the use of higher loadings, improved substrates and improved formulations.

b. High Energy Ignition - HEI assures reliable ignition with air-fuel ratios and EGR rates that may be required for optimum economy. Currently developed systems appear entirely adequate for use on future models.

c. Proportional EGR - Sophisticated EGR systems will be required on an engine optimized for best economy. The EGR system will have to be capable of delivering optimum rates of recirculation over the whole range of engine speed and load. Systems which have been used in the past will have to be changed. While some of the systems previously used were as crude as a hole drilled between the floor of the intake manifold and the exhaust crossover, future systems will consist of modulating valves that are controlled by signals which are proportional to engine load. Several such EGR valves will be used in some 1975 models, particularly for use in California.

d. Improved quick Heat Intake Systems - Some 1975 models will use QHI systems but further improvements over the types of systems being used on the 1975 models are possible. While the QHI system causes slight economy benefits due to the reduced cold start enrichment requirements, the most significant advantage it offers is that it reduces HC and CO emission during the most critical time; the time period before the catalyst has reached light off temperature.

One of the most advanced QHI systems demonstrated to date was developed by General Motors. Called "Super EFE" (EFE = Early Fuel Evaporation), this system achieved .41 g/mi HC and 3.4 g/mi CO without the use of catalysts. Test results reported by GM are tabulated below:

Super EFE - No Catalyst (g/mi)

	HC	CO	NOx
4000# test weight	.37	3.09	1.51
4500# test weight	.43	3.86	1.86
5000# test weight	.49	4.27	2.24

Integrated with a catalyst system Super EFE would allow fuel economy optimization at low emission levels. A basic difference between Super EFE and the QHI systems showing up on some 1975 models is that the intake manifold incorporates a thin, finned plate to increase the rate of heat transfer between the exhaust gas passing through the intake manifold and the intake change whereas the 1975 systems have a thicker cast section that the heat must pass through. The Super EFE system also directs all exhaust gas through the intake manifold on start up, not just a portion of it. A schematic of the system is shown in Figure 4-12.

e. Modulated Air Injection - A considerable amount of data was available that indicated the commonly used air injection systems is not the optimum set-up. Much of this data is compiled in reference 17. The optimum air injection rate is a function of engine load and speed but current systems are only sensitive to speed. Light load conditions usually result in the air injection rates that are higher than optimum while high load conditions usually result in less than optimum rates.

Good data quantifying the adverse effect of excessive air injection rates was not located but data indicating the loss in emission control due to inadequate air injection

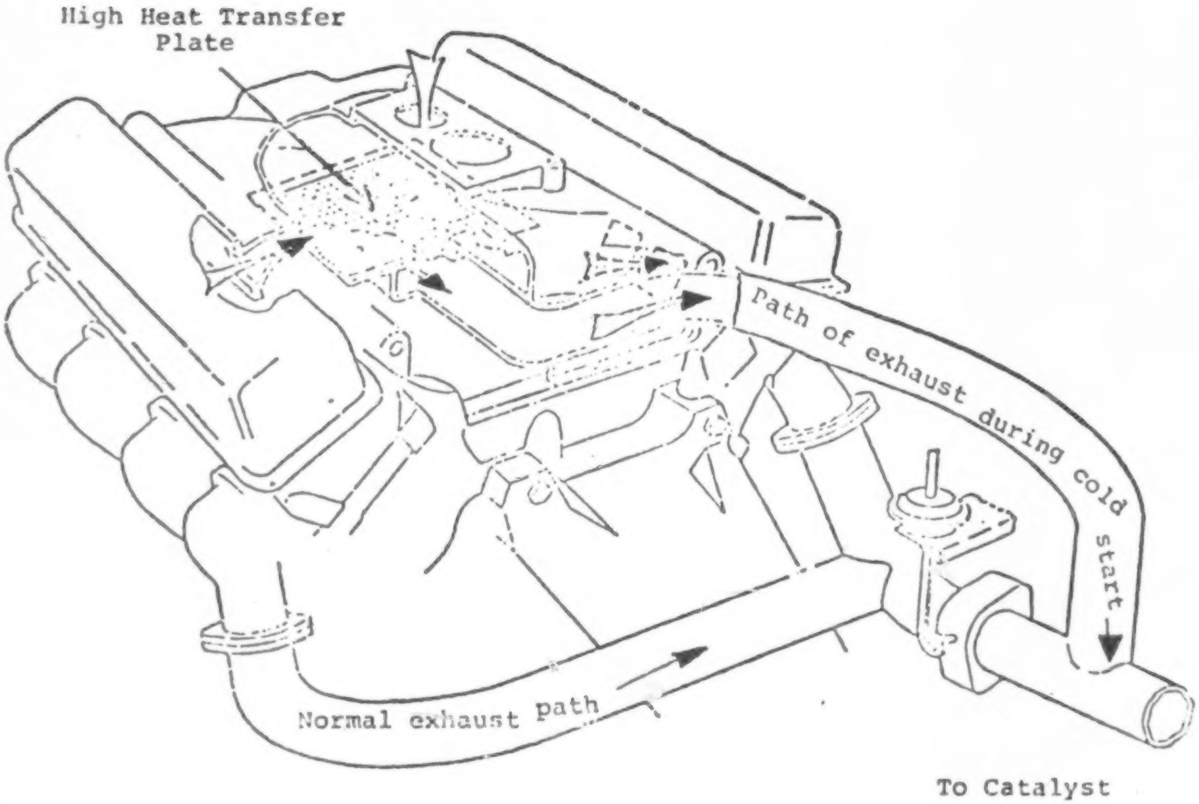

High Heat Transfer Plate
Path of exhaust during cold start
Normal exhaust path
To Catalyst

Figure 1-12 Advanced QHI System (Super EFE)

rates was abundant. HC reductions of 28% and CO reductions of 44% have been shown when higher than normal air injection rates were used. The system used to achieve this level of improvement consisted of a variable drive ratio device attached to the standard 19 cubic inch air pump which GM produces and sells to other manufacturers. The variable drive set up kept air delivery high during low engine speeds.

A more optimum air injection system would includa a higher capacity air pump and a modulating valve. This concept, which has been reported by Toyo Kogyo and Mitsubishi, is relatively simple and inexpensive but highly effective.

f. Cold Start Emission Reduction Systems - Several emission control systems for the reduction of emissions before the catalyst achieves light off temperature have been reported on in the past, and one manufacturer who met with the technology panel reported an active development program in this area. There are two primary systems with high potential: 1) start catalyst system and 2) cold storage system.

The start catalyst concept basically involves using a different catalyst during warm up than during the bulk of engine operation. The catalyst that is only used during warm up is called the start catalyst. The performance criteria for a start catalyst are different than for a main catalyst as shown below and in Figure 4-13.

TABLE 4-13 CATALYST PERFORMANCE CRITERIA

Main Catalyst	Start Catalyst
1. High efficiency after 50,000 miles of exhaust gas	1. Rapid light off
2. Good light off characteristics	2. High efficiency after 10,000 miles of exhaust gas
3. Resistance to high thermal loads caused by extremes in engine loading	

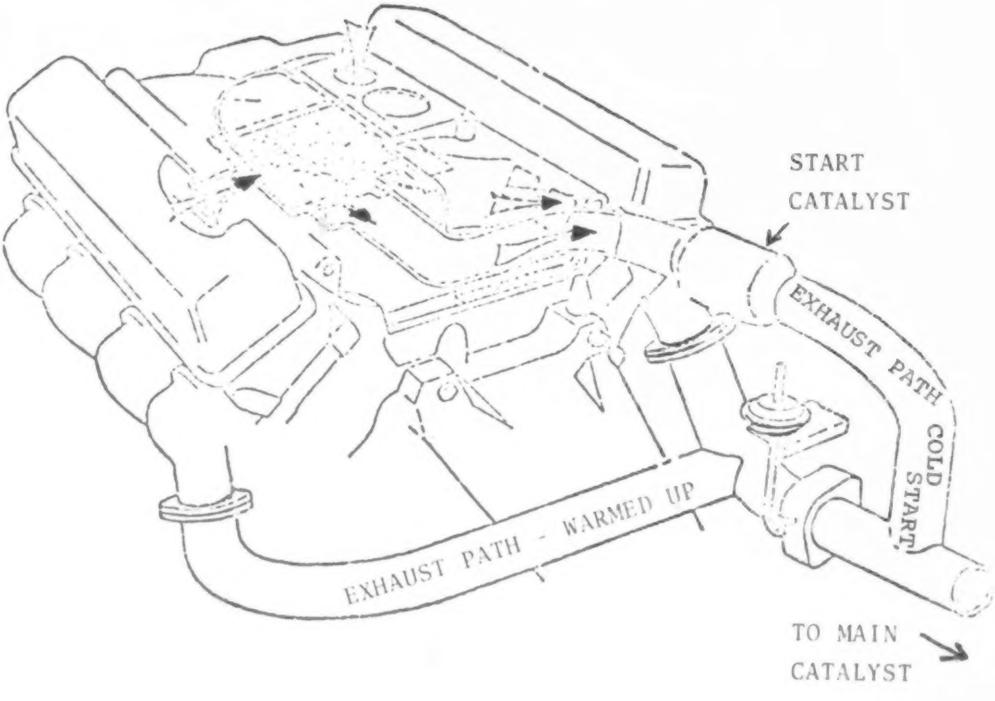

START CATALYST
EXHAUST PATH COLD START
EXHAUST PATH - WARMED UP
TO MAIN CATALYST

Figure 4-13 Start Catalyst System

Not only are the criteria for the main and start catalyst somewhat different, the use of both catalysts allows the light off performance of the main catalyst to be traded off against higher warmed up efficiency. Since the start catalyst does not have to be durable for as long a period of time as the main catalyst, formulations can be chosen which trade off durability performance against low mileage efficiency. Also since the start catalyst does not have to survive under extreme operating conditions such as high speed trailer pulling or have to reduce emissions during high engine loads it can be designed to warm up more rapidly than a main catalyst could. This rapid warm up is greatly facilitated by the fact that the start catalyst can be smaller than the main catalyst because it is used only during the first couple of minutes of vehicle operation before the engine is warmed up to the point where it can generate high exhaust volumes.

Not much data is available on the effect of start catalysts as most manufacturers do not seem very interested in producing a system that is as complex as the start catalyst system. The superiority of the start catalyst approach is well known however as evidenced by the fact that one manufacturer resorted to a start catalyst when it became apparent HC emissions would be a big problem for their rotary engine.

The most effective start catalyst systems would include some sort of catalyst preheat before startup or during startup. A logical source of pollution-free power that could be used to warm up the start catalyst would be the vehicle battery. Electrical heating of most catalysts would be difficult because of the poor thermal conductivity of conventional substrate materials but a possible solution which has been suggested would be to use a metalic start catalyst heated by having current flow directly through it. Complete elimination of the delay period between engine start and catalyst light off would result in reductions in HC and CO levels of approximately 20-50% depending on the percentage contribution of the cold start for a particular vehicle/engine/control system combination.

The cold storage concept is only effective on HC emissions. Since HC emissions seem to be the major problem when trying to optimize for fuel economy, however, it may be a critical part of future emission control systems. The idea of the system is to store hydrocarbon emissions in a charcoal adsorber during cold start and warm up operation. This is similar in concept to the technique currently used to control evaporative emissions but applied here on a larger scale. During the first few minutes of engine operation the exhaust gas is directed through a bed of activated charcoal after it passes through the catalyst. The size of the bed required is approximately equal to the size of the catalytic converter. When the catalyst reaches light off temperature, the air pump is used to purge the hydrocarbons stored in the adsorber into the catalyst where they are very efficiently oxidized. A schematic of the cold storage system is shown in Figure 4-14.

Both Daimler-Benz (Mercedes) and General Motors have experience with the cold storage approach and both have reported data which show the system to be highly effective. As early as 1971 GM reported 30% reductions in HC emissions with the use of this system. Work was stopped on the system because it "requires such complicated pipes and valves -- it is too impractical for production consideration at the present state-of-the-art.[18]

One manufacturer reportedly reactivated cold storage work when it appeared that high HC emissions would keep their rotary engine from certification in 1975. This fact gave some indication to the panel that the cold storage system may not be as impractical as previously indicated, since it was resorted to when the need to certify a particular engine was high.

Figure 4-15, provided by Daimler-Benz, shows an engine's HC emission rate with and without the use of a cold storage system. The cold start HC emissions are essentially wiped out. This obviates the need to employ alternate HC control methods which may have a detrimental effect on fuel economy.

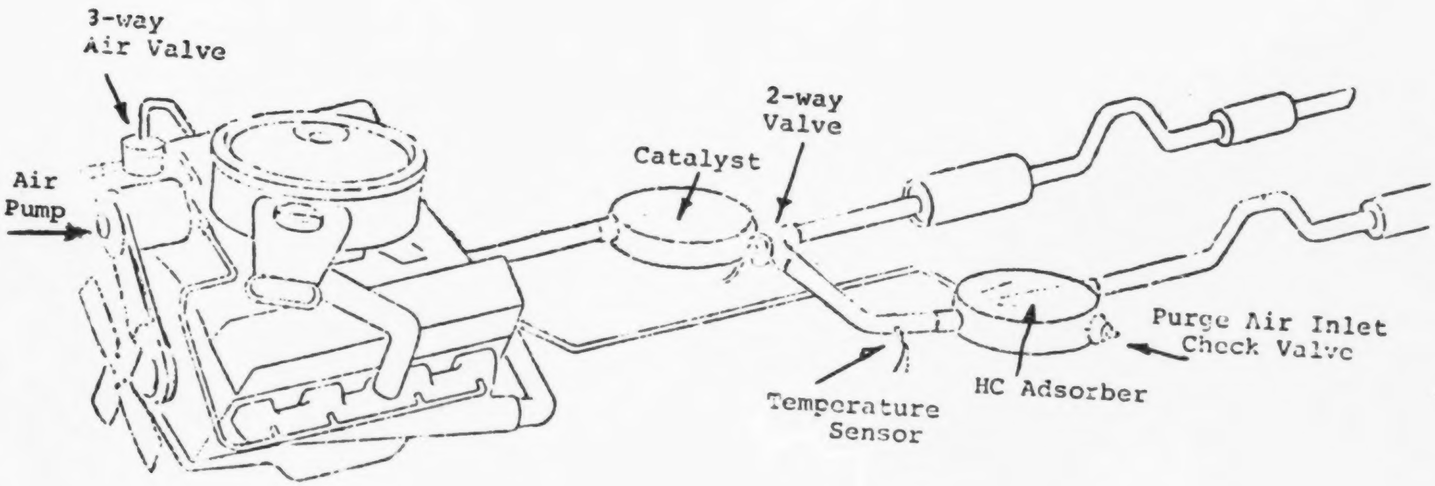
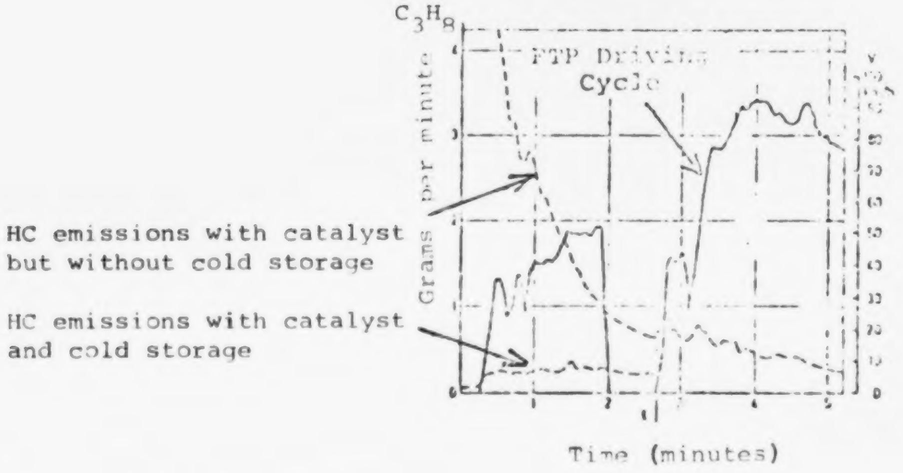

3-way
Air Valve
Air
Pump
Catalyst
2-way
Valve
Temperature
Sensor
HC Adsorber
Purge Air Inlet
Check Valve

Figure 4-14 Cold Storage System



HC emissions with catalyst but without cold storage

HC emissions with catalyst and cold storage

Figure 4-15 HC Emission Rate with and without Cold Storage
(Source: Daimler-Benz)

In summary, improvements in the basic oxidation catalyst plus EGR system that is being used for 1975 appear to be able to allow the achievement of low emission levels with engine calibration that is optimum for fuel economy. At the 0.41 HC, 3.4 CO and 2.0 NOx (g/mi) emission levels, a system employing modulated air injection, and a start catalyst (without supplemental heat) is shown to be capable of doing the job.

At 1.0 gpm NOx the heaviest vehicles may have some difficulty in certifying with this system and supplemental start catalyst heat or a cold storage system may be required to meet the .41 HC level while maintaining optimum engine calibrations. Below 1.0 g/mi it appears the oxidation catalyst and EGR approach will only be feasible for the smallest cars.

As with most of the engine systems investigated by the technology panel, it is difficult to really "prove" that optimum engine calibrations can be maintained in meeting any particular emission level since no vehicle test data was available on systems which were as complete as those the panel felt would best do the job. Strong indications that the advanced devices investigated by the panel would allow the flexibility of engine calibration to be maintained can be seen from a review of the technical appendix to the EPA Administrator's decision on the suspension of the original 1976 emission standards[19]. This rigorous analysis of a large amount of emission data showed 91% of the models currently produced by GM, Ford, Ghrysler and AMC would be capable of achieving .41 Hc, 3.4 CO and 2.0 NOx g/mi if optimum combinations of systems were used in conjunction with engine calibrations that were optimized for low emissions (not high fuel economy). It is the panel's judgement that the use of more advanced systems (such as MAI and start catalysts), which were not assumed in the technical appendix for the 1976 decision, will give manufacturers the capability for calibrations that are optimum for fuel economy at the same emission levels. Absolute proof will not be available until agressive development programs employing the use of advanced systems have been carried out.

4.3.2.2 Lean Burn and Oxidation Catalyst - Until recent developments in EGR technology, the lean calibration approach to improving fuel economy was at the forefront of potential ways to improve the economy of conventional engines. The fuel economy benefit is due to the reduced throttling losses which occur with lean mixtures. Ultra-lean running has also shown promise for simultaneously reducing HC, CO and NOx emissions. HC and CO control is achieved by virtue of the high oxygen concentrations and NOx control is achieved because at sufficiently lean air/fuel ratios the excess air acts as a diluent just as EGR does. As pointed out earlier, achieving lean combustion depends on:

a. Good fuel atomization
b. Even distribution
c. Adequate ignition

When standard engines are recalibrated to run extremely lean, the results are often discouraging because these three things are lacking.

The most significant development in the lean combustion area recently is the development of the Dresser carburetor. This carburetor maintains sonic flow in its throat to achieve high atomization of the fuel as it passes through the shock wave. Dresser reportedly achieves cold starts with leaner than stoichiometric air/fuel ratios, which indicates this fuel system is a giant step forward.

With no after treatment or EGR system Dresser-equipped vehicles have achieved emission levels in range of 1.0 Hc, 5.0 CO, 1.5 NOx (g/mi.). Equipped with only a high volume, insulated exhaust manifold and using spark retard, emissions below .41 HC, 3.4 CO and 2.0 NOx (g/mi.) have been achieved. As with more typical engines, spark retard adversely affects fuel economy. Figure 4-16 shows how the economy of the Dresser vehicles compared to the average 1974 cars and the best 1975's. As can be seen from the figure, nearly identical performance to the best '75's is achieved.

The ultimate potential of the Dresser lean burn approach remains unknown at this time. Dresser has only a small group working on the carburetor and although several auto companies are working with Dresser there is a dearth of data on the system particularly with regard to its compatability with EGR and catalysts. It is impossible to tell as yet whether or not the Dresser system has potential for 0.4 g/mi. NOx.

At the 2.0 g/mi. NOx level integrated into an oxydation catalyst system, it is an attractive alternative to the conventional oxidation catalyst plus EGR system because the "engine-out" HC levels are quite low and advanced control systems such as cold storage and start catalysts do not appear to be required.

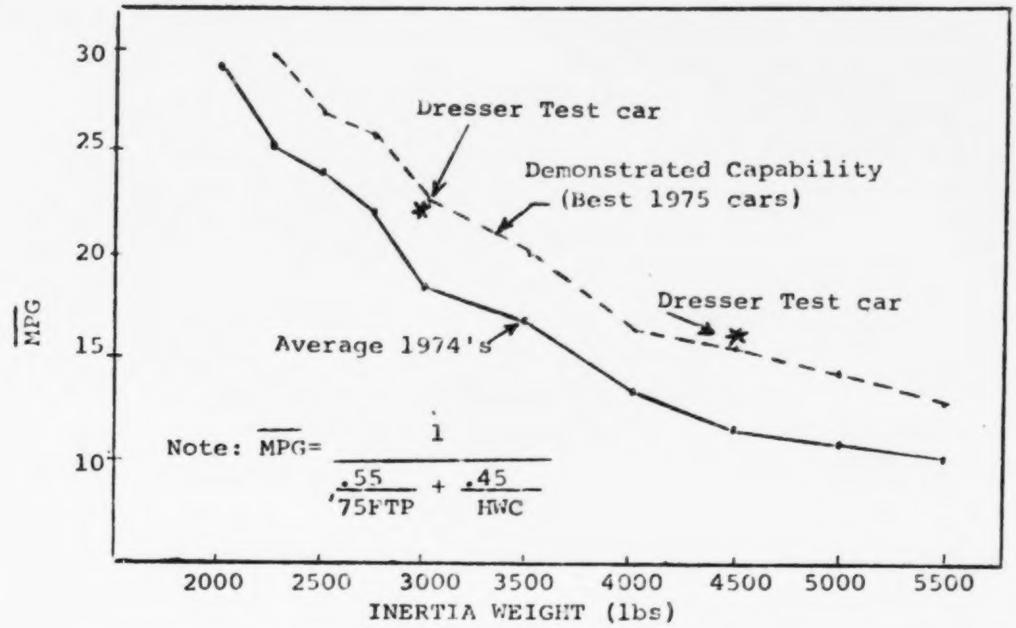


Figure 4-16 Advanced Lean Burn System versus 1974 Average and Best 1975 Data

Impacts

Same as catalyst plus EGR system, except lead time is somewhat longer due to new carburetor tooling required but mass production by 1980 is entirely feasible.

4.3.2.3 Dual Catalyst - Dual catalyst emission control systems for the conventional engine have had a reputation for poor fuel economy, so including such systems in a fuel economy improvement section might seem inconsistent. However, as the preceeding discussion has emphasized, the variables that affect engine fuel economy are all related to basic engine operating parameters and not necessarily related to exhaust emission control after-treatment devices.

The basic engine related reasons why dual catalyst emission control systems have had poor fuel economy in the past are related to the value to which the air/fuel ratio was calibrated and the EGR systems used. Nox catalysts need input air/fuel mixtures deficient in oxygen. This means that the engine typically has been calibrated on the rich side of stoichiometric. However, because of the necessity to reduce lean excursions in the exhaust stream which are detrimental to NOx catalyst durability, some systems have been calibrated richer than necessary to attempt to improve the NOx catalyst durability at a fuel economy penalty. Recent advances in NOx catalyst emission control systems have eliminated the requirement to run excessively rich by introducing a device upstream of the NOx catalyst that reduces lean excursions.[20]

The optimization of an engine equipped with a properly-designed EGR system, as reported in SAE Paper No. 740104 can change the point of best economy for an engine to one different from the point considered optimum heretofore. In fact, the best brake specific fuel consumption point for one set of parameters that gave low engine NOx emissions was approximately an air/fuel ratio of 14.4 to 1, an air/fuel ratio that is satisfactory for NOx catalyst input operation with good NOx conversion efficiency. Especially considering that the baseline (engine-out) NOx emissions will be low with this approach, the dual catalyst system looks much more attractive from both the fuel economy and emissions point of view than it did just a few months ago. Since the engine operating condition can be at optimum BSFC levels there is no reason why a dual catalyst system cannot have the same fuel economy as the advanced oxidation catalyst plus EGR systems discussed earlier.

The major problem foreseen for this concept is HC control. The air/fuel ratio, EGR rate and spark timing necessary to get optimum BSFC from the engine in the dual catalyst system will involve an HC penalty if nothing is done to improve HC emission control. It will be necessary to use one of the advanced HC control devices discussed earlier such as a start catalyst, super EFE, or cold HC storage to make this concept able to meet the 0.41 g/mi. HC standard.

The conclusion reached here concerning the fuel economy potential of the dual catalyst system is bound to be controversial. Since no system like the one described above has been built and tested to date, data validating or disproving the estimates are not available. Such data may not ever be available, because EPA review of manufacturers annual status has indicated virtually all automobile manufacturers have essentially abandoned their development programs targeted toward 0.4 g/mi NOx, and therefore are not pursuing this potentially attractive concept.

The fuel economy improvement percentages for the advanced dual catalyst system used in this report were the same as those used for the advanced oxidation catalyst plus EGR case, namely 25, 20 and 15 percent for the large, mid-size, and small vehicle classes respectively.

4.3.3 Stratified Charge Engines

4.3.3.1 Discussion - The concept of charge stratification in gasoline engines is not new. Some examples of engines employing this principle were proposed around the turn of the century. The characteristic common to all of the stratified charge engines discussed here is that at the time ignition is initiated (by a spark plug) the air/fuel mixture is stratified within the combustion chamber, that is, the air/fuel ratio is different at different locations in the combustion chamber, the region near the spark plug having rich air/fuel ratios and other regions having lean air/fuel ratios.

Two basic types at stratified charge engines were considered for this report; the divided chamber or prechamber type and the open chamber type. In the prechamber type, the combustion chamber is composed of two distinct volumes with a throat or passage connecting them. In the open chamber type the combustion chamber volume is essentially a single one.

4.3.3.2 Prechamber Stratified Charge Engine - Of all of the divided chamber type stratified charge engines, the one chosen for investigation in this report is the prechamber type like the CVCC engine developed by Honda. This engine is carbureted, with a separate induction system and intake valve for each of the two parts of the combustion system. An enlarged exhaust manifold has been used with this system and many of the other prechamber stratified charge engines to provide extra control of HC and CO. No air injection is used.

The fuel economy characteristics of such engines have been a subject of some interest for the past year or so. GM has claimed in its submission to the F.E.A. that the fuel economy is equivalent to a conventional engine with oxidation catalyst and EGR calibrated to the .41 HC, 3.4 CO, 2.0 NOx (g/mi.) level.[21] Ford has reported that the fuel economy benefit compared to 1974 depends on the emission level that the prechamber engine is calibrated to meet, decreasing as the emission levels become lower.

EPA tests of vehicles with prechamber stratified charge engines, calibrated to meet the .41 HC, 3.4 CO, 2.0 NO_x level, indicate fuel economy values equal to or slightly better than the average of the 1974 vehicles in the same weight class.

The panel estimates that the following percent changes due to the use of prechamber stratified charge engines are likely.

TABLE 4-14 PERCENT CHANGE IN FUEL ECONOMY FOR PRECHAMBER STRATIFIED CHARGE ENGINES

Vehicle Type	At the 2.0 g/mi. NO_x Level	At the 0.4 g/mi. NO_x Level
Large	+5%	—
Mid-size	+3%	—
Small	+0%	-20%

The estimates are given for prechamber stratified charge engines without oxidation catalysts. The panel estimate that some degree of spark retard away from MBT will be used as a hydrocarbon control technique, primarily for these engines. No estimates are shown for the large and mid-size vehicles at the 0.4 g/mi NO_x level, since that degree of control has not yet been demonstrated on vehicles of that size.

4.3.3.3 Open Chamber Stratified Charge Engines - Two major types of open chamber stratified charge engine are now under development, the Ford PROCO engine and the Texaco TCCS engine. Both concepts use direct cylinder fuel injection, but differ in that the PROCO engine has high squish-air motion, while the TCCS engine relies on swirl with programmed fuel injection and ignition to maintain a nominally stationary flame front.

The PROCO engine has been chosen for use as an open chamber stratified charge engine since the panel judged it to be more developed than the TCCS engine, with greater potential for actual use, since a major automobile manufacturer is developing it, and because its fuel economy potential is high, even when calibrated to meet low HC and NO_x levels.

Ford reported in (Ford '73 Status Report) that a 4500 pound vehicle obtained approximately 33 percent better fuel economy compared to the average 4500 pound car.[22] The fuel economy was not affected by NO_x level from below 0.4 to above 1.0 g/mi. NO_x. Tests conducted by SwRI for the EPA on a 2500 lb. vehicle shows an 18 percent gain compared to the average 1974 2500 pound vehicle. A.D.L. estimated that an open chamber stratified charge engine would have an 18 percent improvement in fuel economy[3]. SwRI estimated that a 4500 lb. vehicle would have a 34 percent improvement, if equipped with an open chamber stratified charge engine.[2]

The estimates used by the panel for the open chamber stratified charge engine, based on the PROCO performance are shown below. The estimates are the same at both NO_x levels considered.

Vehicle Type	Percent Charge in Fuel Economy
Large	+25
Mid-size	+25
Small	+15

4.3.3.4 Lead Time and Cost - Ford has said that the earliest that a single line or stratified charge engine could be available is 1978, and only if some of their desires on emission standards are fulfilled. The initial cost increment and investment for one production line are shown below:

Vehicle Type	1st Cost Increment	Investment Millions	Stratified Charge Engine % Usage by 1980
Large	$250	$30	less than 10 percent
Mid-size	$240	$30	less than 10 percent
Small	$200	$30	less than 10 percent

The major potential lead time stumbling block for this concept is the production design and fabrication of the fuel injection equipment.

4.3.3.5 Natural Resources Impact - No significant impact on natural resources was identified with we of the open chamber stratified charge engine.

4.3.3.6 Safety Impact - No major safety - related impacts are foreseen with use of the open chamber stratified charge engine.

4.3.3.7 Emissions Impact - The major problem with open chamber stratified charge engines like the PROCO is hydrocarbons. NO_x can be controlled to below 0.4 g/mi. with EGR alone, with no apparent adverse fuel economy problems. Hydrocarbons are high and advances in catalyst HC efficiency and/or advanced HC control and charcoal canisters will be needed for the open chamber stratified charge engine to successfully certify at 0.41 g/mi. HC.

4.3.4 Diesel Engine

4.3.4.1 Discussion - Like the stratified charge engine, the Diesel engine is not a new concept, being first proposed in 1892. Diesel engines are in widespread use today whereever efficient power generation is required. Diesel engines power ships and boats, heavy duty trucks, construction equipment, farm equipment and some automobiles.

Diesel engines differ from conventional gasoline engines in the way air and fuel are mixed, in the mechanism by which the air/fuel mixture is ignitied, and in the way the power output of the engine is varied. The differences are shown below:

	Diesel	Conventional
Air/Fuel Mixing	Fuel is injected directly into compressed air in the cylinder	Fuel is mixed with air in the carburetor and induction system outside the cylinder
Ignition	Hot, compressed air ignites air/fuel mixture	Air/fuel mixture ignited by a spark from a spark plug
Load Control	Power output controlled by amount of fuel injected	Power output controlled by a throttle

Diesel engines are more efficient than conventional gasoline engines because the compression ratio used in Diesel engines is much higher than the compression ratio in conventional gasoline engines, and also because the Diesel does not have a throttle, so the pumping losses are reduced dramatically, expecially at part load, compared to the conventional gasoline engine.

Currently available automobiles equipped with Diesel engines achieve fuel economy values more than 65% higher than the average 1974 automobiles of equivalent weight, equipped with conventional gasoline engines. The automobiles currently equipped with Diesel engines, however, have poorer performance than the automobiles equipped with conventional gasoline engines. For comparisons made on an equal performance basis, some estimates have been made of diesel engines with power more nearly equivalent to that of gasoline engines.

References ADL Report[3], SwRI Report[2] and Ricardo Report [23] all give estimates of the fuel economy of diesel engines of increased horsepower compared to today's automobile diesel engines.

For this report the ways to increase the power have been grouped into two approaches, increased displacement alone, and use of boost, i.e., increasing the inlet manifold pressure, also with an increase on displacement.

4.3.4.2 Increased Displacement - Naturally Aspirated Engine - One way to increase the power of a Diesel engine is to increase its displacement. For the three classes of vehicles considered in this report, the range of displacements considered for a naturally-aspirated Diesel engine of equivalent performance is shown below:

Vehicle Type	Displacement Required
Large	326 to 378 cubic inches
Mid-size	237 to 290 cubic inches
Small	158 to 188 cubic inches

These displacement are nearly the same for the large vehicle, but somewhat larger for the mid-size and small vehicles, compared to conventional gasoline engines.

For a naturally aspirated Diesel, the percent improvement in overall fuel economy for two vehicle types are as follows:

	Fuel Economy Improvement		
Vehicle Type	Data From Ref (3)	Data From Ref (2)	Data From Ref (23)
Large	+20%	+35%	-
Mid-size	+25%	-	46%

Since Diesel fuel has a greater energy content per gallon, the corresponding figures for the above table on a miles per BTU basis, using 137,000 BTU/gallon for Diesel fuel and 124,500 BTU/gallon for gasoline are shown below.

Range of Miles/BTU Improvement

Vehicle Type	Data From Ref (3)	Data From Ref (2)	Data From Ref (23)
Large	+9.5%	+23%	-
Mid-size	+14%	-	+33%

Even though economy gains can be shown for the naturally-aspirated diesel, some problems will remain. Using today's technology, a naturally-aspirated diesel will be significantly heavier and somewhat bulkier than a conventional gasoline engine of equal power. Use of light alloy construction may reduce the weight penalty somewhat, but not eliminate it. The estimated weight penalties with weights for the conventional engine of 600, 450 and 340 pounds, respectively, for the large, mid-size and small class vehicles are as follows:

Vehicle Type	Ref (2)	Ref (2)	Ref (23)
Large	+ 20 lb	+500 lb	-
Mid-size	+120 lb	-	+250 lb
Small	-	-	-

For the small class the penalty is estimated to be about 265 pounds based on a nominal 173 C.I.D. engine of 3.5 lb/CID. Because of the above weight penalties, the naturally aspirated Diesel was not carried through to the synthesized vehicle stage. It is, however, the lowest risk approach, if the weight penalties are accepted, since it is the most like current conventional Diesel automobile engine except for size.

4.3.4.3 Turbocharged Diesel Engine

Another way to increase the power of a Diesel engine is to increase the pressure in the inlet manifold with a supercharger or turbocharger. Since the turbocharger is the most widely used method of boosting Diesels, that concept has been used here.

Turbocharging allows increases in horsepower per cubic inch of displacement and horsepower per pound of engine weight, compared to a naturally-aspirated engine of the same power. The degree of improvement depends to a large degree on the boost pressure ratio (BPR). SwRI[2] used a higher BPR than was used in the Ricardo Report[23] but the BPR of 1.5 used in the former is considered well within the state of the art, since heavy-duty engines run with BPR's significantly above 1.5 now, and for passenger car use the amount of time spent at maximum power is small.

The characteristics of the engine chosen for consideration are those of the Southwest Research Institute[2] (SwRI), namely 260 cubic inches, turbocharged to a BPR of 1.5, for use in the large vehicle, producing approximately 150 horsepower. For the mid-size and small vehicles, the necessary displacement were estimated to be approximately 200 and 140 cubic inches, respectively. The weight penalty, for the Diesel in the turbocharged version is shown below for conventional materials.

Turbocharged Diesel

Type Vehicle	Weight Penalty Pounds	Engine Weight Penalty Percent
Large	45	7%
Mid-size	70	16%
Small	40	12%

The weights were estimated from the weights of naturally-aspirated engines of equal displacement, since the structure requirements could be about equal for a successful passenger vehicle engine application. SwRI estimated that the weight penalty could be reduced to approximately 10 percent with further development, but also mentioned that this was likely only after one or two successive engine designs had been thoroughly evaluated.

The weight penalties for both Diesel configurations were based on today's installed horsepower per pound for conventional gasoline engines. There may be a trend starting toward lower horsepower per pound engines for gasoline engines. For 1975 some of the lower-powered gasoline engined vehicles will have power to inertia weight ratios between .024 to .028. Since one example of increased displacement Diesel will have a power to inertia weight of .022, the Diesel will become more competitive, if the lower-powered gasoline engined vehicles find acceptance in the market place.

The fuel economy improvement, on a percentage basis, for the three vehicle types used in this report is shown below:

Vehicle Type	Turbocharged Diesel Improvement in Fuel Economy (mpg basis)
Large	+50%
Mid-size	+45%
Small	+35%

The percentage improvement on a miles per BTU basis would be 37 percent, 32 percent, and 23 percent, respectively, for the three vehicle types.

The smaller engines show less improvement because the percent of friction horsepower generally tends to increase as the engine size goes down, and friction horsepower is important for Diesel engines. Another reason for the lesser improvement is of course the fact that current light weight cars have not been penalized by emission controls so there are lesser improvements possible than is the case for heavier cars.

4.3.4.4 Lead Time and Cost - Considering the current status of passenger car Diesel engine development in the domestic industry, a development time of 30 months has been considered an optimisitc minimum for development of a Diesel engine of the type considered in this report. This would probably involve a joint effort between domestic automobile manufacturers and either domestic heavy-duty Diesel manufacturers or foreign light duty Diesel manufacturers.

A concurrent joint manufacturing program for Diesel engine fuel injection equipment and turbochargers would also be necessary, again with the domestic manufacturers combining with other firms that have more expertise.

A production time estimate, once the development has finished is estimated to be approximately 36 months as a minimum, possibly somewhat longer than for a typical new conventional engine since the fuel injection equipment and turbocharger manufacturing will be new for the domestic manufacturer at the production volumes required. The major engine-related items and manufacturing equipment for blocks, heads, crankshafts, should be much closer to current practice.

The lead time estimate for a turbocharged diesel engine is shown below:

Development Time	30 months
Production Time	36 months
Total Lead Time	66 months (5.5 years)

As can be seen from the above estimates, a Diesel engine just might be available before 1980 if a concentrated development program were undertaken now. However, no such program was reported by any domestic manufacturer, so the chances for a domestically-produced Diesel before 1980 appear slim. The Diesel engine has been included in the analysis because of its fuel economy potential in the post-1980 time frame.

The National Academy of Science (NAS)[24] gives the total sticker price increment for a Diesel-engined automobile as ranging from \$145 to \$850 depending on the vehicle type. Reference (2) estimates the extra cost for the turbocharged engine alone to be between \$200 and \$300 for the large size vehicle. The Ricardo Report[23] estimates the extra cost for a small turbocharged engine to be approximately \$240.

The first cost increment for a Diesel-engined vehicle and investment cost (in millions of dollars per engine line) for a Diesel engine as used in this report are shown below:

Vehicle Type	Diesel Engine First Cost Increment, Dollars	Investment Cost Millions of Dollars For One Engine Line
Large	+$385	140
Mid-size	+$315	140
Small	+$260	140

4.3.4.5 Natural Resource Impact - The primary impact of the Diesel on natural resources would be a somewhat increased demand for the cast iron used in its construction, due to the Diesel's extra weight. The requirement for materials that are used in the catalytic converters for conventional gasoline engines will be reduced as more Diesels are introduced.

4.3.4.6 Safety Impact - Since the Diesel engine equipped vehicles will have the same nominal power to weight ratio as current vehicles, safe power requirements for passing, for example, should be met. The response of the turbocharged engine will have to be subject of development effort to reduce the lag to acceptable levels. Vehicle brakes will have to be uprated somewhat to provide the same braking capability with the heavier engine, and development work is required to ensure that the vacuum pump that may be used for the power brakes is reliable.

Engine mounting and deflection systems may have to be designed or redesigned especially for the Diesel in light of the barrier crash requirements. The other safety related area influenced by the Diesel is that of fires. Since Diesel fuel is typically much less volatile than gasoline, the incidence of vehicle fires should be reduced with increased use of Diesels.

4.3.4.7 Emission Impact - Currently available Diesel automobiles have no trouble meeting the current Federal and California interim standards, and one manufacturer of a Diesel engine will certify for 1975 below the current 1977 standards of .41 HC, 3.4 CO, 2.0 NOx (g/mi.). No major difficulties are foreseen in having the turbocharged Diesel concept discussed in this report meet the .41 HC, 3.4 CO, 2.0 NOx (g/mi.) standards.

The biggest unknowns in the Diesel engine emission area are in unregulated emissions and in low NOx achievement.

Sources of concern with Diesel engines include three main emission-related characteristics which are currently unregulated: exhaust smoke, odor, and particulates.

Smoke from Diesels is currently regulated for heavy duty vehicles, but not for light duty Diesel vehicles. Smoke is a nuisance from Diesel engines but current low emission Diesels appear to have acceptable smoke levels. The smoke level with the turbocharged engine discussed in this report should be better than current Diesel automobiles if care is taken to match air and fuel delivery.

Odor from some Diesels can be quite objectionable. The Diesel has been associated with high odor level in the U.S. due to the particularly bad performance of Diesel engines that were popular in busses until recently. However, some current Diesel passenger cars have odor levels that are as low as some gasoline engine vehicles. Turbocharging can also help odor performance.

Particulates are higher on a total mass basis from Diesel-engined vehicles. Typically, Diesels have more than twice the particulate emissions than gasoline-engined vehicles using leaded fuel and more than ten times the particulate emissions than gasoline-engined vehicles using unleaded fuel. This potential problem is one of the reasons given by some manufacturers for not proceeding quickly with a Diesel engine development program, since a low particulate emission standard on a total mass basis would be hard for the Diesel to meet.

Another problem, and a reason why some makers are reluctant to work on diesels is the feeling that the 0.4 g/mi. NO_x level cannot be attained. The 0.4 g/mi. NO_x level has been met with a modified mid-size vehicle at low mileage, but the fuel economy characteristics of such modified Diesel vehicles are unknown. More work will be necessary to fully evaluate the potential of the Diesel at the 0.4 g/mi. NO_x level and the amount of time necessary for development for domestic production put this type Diesel into the 1980's before it could be introduced by a domestic manufacturer, if indeed a serious development program ever even gets started.

Another potential problem with the diesel may be the distribution network, (not the capability to supply fuel) for the diesel fuel.

4.4 ACCELERATION PERFORMANCE REDUCTION

Automobile engines generally have sufficient power capacity to accelerate rapidly, to pull trailers, or to maintain high speed on moderate grades. The penalty for this kind of acceleration margin appears as reduced fuel economy. One option for improvement of fuel economy is to reduce acceleration performance to the level provided in small cars. The effect is to increase from 12 seconds to 20 seconds the time needed to accelerate from 0 to 60 mph. For large cars the fuel economy improvement would be about 20% and in the range of 10% for mid-size cars. There would be no improvement in the fuel economy of small cars unless the acceleration performance is degraded even more. About 5-10% reduction in engine displacement can be obtained with relative ease by changing the engine stroke. In addition, a given engine design can be "de-bored", that is, the cylinder bore diameter can be slightly reduced. Beyond those changes, new engines would be required. A uniform industry-wide reduction in acceleration performance would probably require increased production of small engines (and simultaneous reduction of the production volume for very large engines). Nevertheless, this option appears to be possible for MY 1980.

The panel feels that the adoption of the reduction performance option which is open to manufacturers would depend on their perception of market acceptability.

Typical weight to engine displacement ratios and the sensitivity of fuel economy to weight/CID changes as predicted by computer simulations[1] are shown in Tables 4-15 and 4-16. The nominal improvement in fuel economy due to reduced performance is in the panels judgement: Large size cars +15%; Mid-size cars +10%; and small cars 0%.

TABLE 4-15 TYPICAL WEIGHT TO CID RATIOS

Vehicle Type	Weight/CID-Domestic	Weight/CID-Import
Standard	12.1	
Intermediate	13.2	
Compact	13.5	25.2
Subcompact	19.0	24.
Specialty	12.5	

TABLE 4-16 SENSITIVITIES OF TYPICAL VEHICLES TO REDUCTION IN ENGINE SIZE

Vehicle Inertia Wt.-Lbs.	Baseline CID	Sensitivity-EPA Composite Driving Schedule*
2000 (man.)	100	0.34
2750	140	0.27
3000	155	0.35
3000	250	0.44
3500	250	0.42
3500	318	0.50
4000	350	0.47
4500	350	0.51
4500	350	0.57
5000	400	0.50

$$* \ \text{Sensitivity} = \frac{\%\ \text{change in fuel economy}}{\%\ \text{change in CID}}$$

5. SYNTHESIZED PASSENGER CARS

Estimates of fuel economy performance of vehicles incorporating selected improvements discussed in Section 4 have been made to investigate various aspects of the practicability of fuel economy improvement standards. Automobiles with the precise combination of individual improvements judged most favorable by the technology panel have not been built and tested, therefore the summary estimates are not supported by definitive test data. The panel believes, however, that test data supporting the integrated conclusions will soon be forthcoming as industry continues to incorporate alternative means into production for improving automobile fuel economy.

5.1 SELECTION OF IMPROVEMENTS FOR 1980

5.1.1 Vehicle Improvements

5.1.1.1 Weight - A weight reduction equal to one half of the weight difference between the lightest and average car in each 1974 class was estimated to be achievable by 1980 for the following reasons:

a. Impact on vehicle styling would be minmized, therefore market demand impact should be minor.

b. With this level of weight reduction the popular engines used in 1974 would still be acceptable, i.e., 350 V-8's would not be too big and therefore the tooling and transfer equipment industry would not be overloaded with work.

c. A major manufacturer had indicated that this level of weight reduction could be and would be achieved by 1980.

d. Extensive materials substitution programs could accomplish this goal without the need for a complete re-design.

Therefore a 10% weight reduction was assumed but only for the mid size and large size classes. For small size cars which are already weight efficient, no weight loss was assumed practical by 1980. About a 5% weight penalty due to additional safety/damageability and emission control hardware was allowed for, with redesign and materials replacement assumed to offset it.

The estimated weight changes and their nominal impact are shown below:

Weight Changes - 1980

	Large	Mid-size	Small
% weight change	-10%	-10%	0
Economy effect	+8%	+7%	0

5.1.1.2 Aerodynamic Drag - Minor re-styling for lower aerodynamic drag was assumed for 1980. Principal reasons were:

a. Negligible frontal area change was assumed in order to prevent adverse impacts on the passenger compartment.

b. Drag coefficient changes were held to 10% reductions to prevent restricting styling flexibility or necessitating major tooling changes.

The nominal changes and their impact are summarized below:

Aerodynamic Drag Changes - 1980

	Large	Mid-size	Small
% change aero drag	-10%	-10%	-10%
Economy effect	+1.5%	+1.5%	+1.5%

5.1.1.3 Rolling Resistance - 100% conversion to radial tires was assumed for the following reasons.

a. Radial tires have no adverse impact other than a minor cost penalty.

b. Radials have major beneficial impacts besides improved economy (e.g., tread life, handling, puncture resistance).

c. The market is headed toward 100% radials already.

The nominal changes and their impact are shown below:

Rolling Resistance Changes - 1980

	Large	Mid-size	Small
% change Rolling Resistance	-------- 100% use of radial tires -------		
% change economy	2.5%	2.5%	2.5%

5.1.2 Transmission Improvements

5.1.2.1 Extra Gear or Overdrive - For vehicles with manual transmission an extra gear or overdrive is a most practical means of improving fuel economy.

The nominal changes and impact are shown below:

Extra Gear - 1980

	Large	Mid-size	Small
Change	Not applicable	Not applicable	Add 1 gear
Economy effect	Not applicable	Not applicable	+4%

5.1.2.2 Extra Gear and Lock-up in High Gear - This modification was judged applicable to all vehicles using automatic transmissions. It was selected because:

a. Work is already underway on this modification by several manufacturers.

b. Minimum driveability or emissions impact is expected compared to lock-up on all gears but low.

c. There is low risk associated with this concept. Higher risk alternatives exist such as CVT.

The impact is shown below:

Extra Gear and Lock-up on High

	Large	Mid-size	Small
Economy effect	+8.7%	+8.7%	+8.7%

5.1.3 Engine Improvements

The conventional engine was assumed for widespread use in 1980. Given the current research and development efforts on the stratified charge and diesel engines, there is inadequate lead time to bring alternative engines on stream in significant quantities by 1980.

Fuel economy optimization of the conventional engine was considered possible by 1980 with new emission control systems at any emission level down to .41 HC, 3.4 CO, 0.4 NOx g/mi. for the following reasons:

a. The progress to date toward achieving 0.4 NOx g/mi. is encouraging, in the light of the very little effort being exerted by the major automobile manufacturers at present.

b. Proportional EGR and some calibration techniques for optimum fuel economy result in very low NO_x feed gas levels with exhaust gas that is compatable with dual catalysts.

c. Prototype demonstration of advanced hydrocarbon control systems have been extremely successful considering the amount of R&D time expended. These advanced systems appear to offer the capability of using the engine optimization techniques described above without exceeding the 0.41 g/mi. HC limit.

d. Lead time by 1980 is not a problem for the approach considered likely.

The nominal impact of an optimized conventional engine is shown below:

	Large	Mid-size	Small
Economy effect	+25%	+20%	+15%

5.2 SELECTION OF IMPROVEMENTS FOR 1985

5.2.1 Vehicle Improvements

Weight - For the 1985 case the average car was assumed to become as weight efficient as the more weight efficient 1974 models. Materials replacement was not assumed. This would leave the use of alternate materials as an option available to each manufacturer to insure a greater degree of design flexibility. These weight changes do not include the effects of more stringent barrier crash requirements. The nominal weight changes and their impact are shown below.

Weight Changes - 1985

	Large	Mid-size	Small
%weight change	-20%	-18%	-17%
Economy effect	+16%	+13%	+10%

5.2.1.1 Aerodynamic Drag - More extensive restyling than assumed for the 1980 case is assumed here. Again frontal area is left unchanged but the drag coefficient reduction goes to 20%.

Aerodynamic Drag Changes - 1985

	Large	Mid-size	Small
% change aero drag	-20%	-20%	-20%
Economy effect	+3%	+3%	+3%

5.2.1.2 Rolling Resistance - No further changes assumed.

5.2.2 Transmission Improvements

Although successful development of the continuously variable transmission is possible by 1980, attaining the operational efficiency necessary to increase driveline efficiency beyond the capabilities of a 4-speed with high gear lock-up is still considered high risk. Therefore, no further improvements over the 1980 case were assumed.

5.2.3 Engine Improvements

5.2.3.1 Diesel Engine - The 1985 timeframe provides sufficient lead time for the development and production of an advanced light weight diesel engine with low noise and odor. Major development efforts will be needed in the area of NOx control. Particulate emission control may also have to be developed if further health effects studies associate Diesel particulate with potential air quality problems. While the development program must be considered high risk, it was factored into the Synthesized Vehicle because:

a. The technology panel concluded inadequate R&D efforts have been exerted to rule the Diesel out as a long-term contender.

b. The economy expected from the Diesel is similar to that expected from the Stirling engine which may be developed for limited introduction by 1985. Therefore, the economy case for the Diesel-powered synthesized vehicle will provide consideration for the capability of potential longer-term solutions as well.

The nominal impact of the Diesel engine assumed is:

	Diesel Engine - 1985 Large	Mid-size	Small
Fuel Economy effect (mpg basis)	+50%	+45%	+35%
Fuel Economy effect (Btu basis)	+37%	+32%	+23%

5.3 COMBINING IMPROVEMENTS

Caution was exercised in determining the combined effect of selected individual improvements. Within each of the major improvement areas (road load reduction, driveline, engine) the impact of a change of one parameter on the other parameters was evaluated. For example, the impact of a suggested change in aerodynamic drag on vehicle weight was determined. Consideration of such impacts led to the elimination of several potential improvements from consideration. An example of this was the case of aerodynamic drag reduction. Preliminary consideration was given to reducing frontal area as a means of cutting aerodynamic drag. The impact such a modification would have, however, indicated that passenger compartment room would be adversely impacted unless the vehicle was lengthened. The increase in length would have increased vehicle weight sufficiently to not only negate any fuel economy benefit but perhaps cause a loss.

To avoid problems within the engine improvement area, no combining of any improvement data was used. The good features of one engine concept were kept completely separate from any other engine concept. Only data from complete engine systems was considered.

In combining improvements from the three individual categories, the impact of a change one category had on the other categories was taken into account. The use of a Diesel engine resulted in a negative weight impact which was considered. The type of data used to determine the effect of rolling resistance reduction accounted for the adverse impact on engine efficiency that resulted from the reduced power demand.

Consideration of all possible trade offs and synergistic effects resulted in the establishment of individual improvement factors that were subjected to computer analysis.[1] Several computer simulations were run to determine the way the major individual improvements combined. From analysis of these simulations the panel has decided to combine the individual improvements arithmetically since this approach is the one indicated by the computer simulations. Tables 5-1 and 5-2 give the results of the computer simulations.

TABLE 5-1 EFFECT OF COMBINING INDIVIDUAL IMPROVEMENTS
(ALL VALUES IN PERCENT)

		Driving Schedule		
Case No.	Type of Change	EPA Urban	EPA Hwy	EPA Comp.
1	10% Wt. Reduct.	2.7	2.1	2.5
2	10% CID Reduct.	4.0	4.5	4.2
3	20% Wt. Reduct.	5.4	4.2	5.0
4	20% CID Reduct.	8.1	9.0	8.4
5	4-sp. Auto; Lock-up			
6	3 and 4	4.2	21.4	9.7
7	(1 and 2)	6.9	6.5	6.8
8	(3 and 4)	13.7	13.0	13.7
9	(4 and 5)	13.9	30.6	19.3
10	(1, 2 and 5)	12.6	29.9	18.0
11	(3, 4 and 5)	22.6	39.2	27.9

TABLE 5-2 EFFECT OF COMBINING IMPROVEMENTS
(ALL VALUES IN PERCENT)

Case No.	Type of Change	Driving Schedule EPA Urban	 EPA Hwy	 EPA Comp.
1	Lean Mixture Engine *	22.8	21.4	22.1
2	Norm. Aspirated Diesel *	57.2	45.8	52.7
3	4-Sp Auto;Lock-up 4th	2.8	20.7	8.6
4	(1 and 3)	26.6	43.6	32.3
5	(2 and 3)	60.8	63.6	61.8

5.4 SUMMARY OF COMPOSITE IMPROVEMENTS FOR 1980

Table 5-3 summarizes, under several composite systems of technical change, conclusions with respect to fuel economy improvements that have reasonably good prospects of being incorporated in the 1980 model year cars in the three classes. Tables 5-4, 5-5, and 5-6 present emissions, incremental first cost, and incremental maintenance cost data for each class for each system. These tables also provide the average fuel economy of 1974 model year cars in the three size classes. The fuel economy figures are representative of typical driving in the United States and are based upon a composite of fuel economy measured under city and highway driving schedules. The tables also give the present market shares of the size classes and an estimate of the maximum shift in market share toward the small size cars. The capacity to shift production toward smaller cars is governed mainly by limitation in the machine tool industry. No assessment of the market demand for smaller cars is implied by these statements.

Table 5-7 summarizes the differences in emissions, fuel economy, first cost, and maintenance cost of the principal engine systems considered relative to the 1974 baseline, as they affect the large size vehicles. Emission levels range from the 1974 levels of 3.0 g/mi of hydrocarbons, 28 g/mi carbon monoxide and 3.1 g/mi oxides of nitrogen to the statutory 1978 requirement of 0.41 HC, 3.4 CO and 0.4 NO_x (g/mi.).

* Based on "paper design" engine maps.

TABLE 5-3 SUMMARY OF SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
(1980 VEHICLES)

System*	Large Size		Mid-Size		Small Size	
	FE(%)	FE(mpg)	FE(%)	FE(mpg)	FE(%)	FE(mpg)
Ref. EPA Composite 1974 Vehicle Fuel Economy	0	10.7	0	13.1	0	22.3
1. Improved Engine	+25	13.4	+20.0	15.7	+15.0	25.6
2. System 1 + auto.trans. w/4 spd. + lock-up	+33.7	14.3	+28.7	16.9	+23.7	27.6
3. System 2 + radial tires + wt.red. + aero drag red. + acces. improvement.	+47.1	15.7	+41.1	18.5	+29.1	28.8
4. System 3 with engine resized.	+62.1	17.3	+51.1	19.8	+29.1**	28.8**

*See discussion for explanation of terms.

**System 4 identical to system 3, engine not resized.

NOTES:

1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.

TABLE 5-4 SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT 1980 VEHICLE - LARGE SIZE

Systems*	Emissions (gm/m) ($HC/CO/NO_x$)	Δ FE(%)	FE(mpg)	Δ First Cost (1974 $)		ΔMaint. Cost 50,000 mi. (1974 $)
				$0.4\ NO_x$	$2.0\ NO_x$	
Ref. EPA composite 1974 vehicle fuel economy		0	10.7	-	-	-
1. Improved Engine						
a. Dual CAT/MAIR/SEFE PEGR/charcoal/HEI	.41/3.4/0.4	+25.0	13.4	+400	--	-186
b. OXCAT/MAIR/SEFE PEGR/HEI	.41/3.4/2.0	+25.0	13.4	--	+233	similar
2. System 1 + auto. trans. w/4 spd. + lock-up	--	+33.7	14.3	+400	+249	similar
3. System 2 + radial tires + wt. red. + aero drag red. + access. improvement.	--	+47.1	15.7	+316	+159	-286
4. System 3 with engine resized to give lower accel. perf.	--	+62.1	17.3	+276	+119	similar

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. 1974 production volume: 2.8 million automobiles, 27%.
4. Projected 1980 production share for maximum shift to small cars = 10%.

TABLE 5-5 SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
1980 VEHICLE - MID-SIZE

System*	Emissions (gm/m) (HC/CO/NO_x)	Δ FE(%)	FE(mpg)	ΔFirst Cost (1974 $)		ΔMaint. Cost 50,000 mi. (1974$)
				0.4 NO_x	2.0 NO_x	
Ref. EPA composite 1974 vehicle fuel economy		0	13.1	--	--	
1. Improved Engine						
a. Dual Catalyst MAIR/SEFE/PEGR/ Charcoal/HEI	.41/3.4/0.4	+20.0	15.7	+291	--	-156
b. OXCAT/MAIR/SEFE/ PEGR/HEI	.41/3.4/2.0	+20.0	15.7	--	+190	similar
2. System 1 + automatic transmission w/4 speed + lockup	--	+28.7	16.9	+305	+204	similar
3. System 2 + radial tires + wt. reduction + aero drag reduction + access. improvement	--	+41.1	18.5	+245	+144	-232
4. System 3 with engine resized to give lower acceleration performance	--	+51.1	19.8	+215	+114	-232

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. Production volume in 1974: 4.7 million automobiles, 45%.
4. Projected 1980 production share for maximum shift to smaller cars = 50%.

TABLE 5-6 SYNTHESIZED VEHICLE FUEL ECONOMY IMPROVEMENT
1980 VEHICLE - SMALL SIZE

System*	Emissions (HC/CO/NO_x (gm/m))	Δ FE(%)	FE(mpg)	Δ First Cost (1974$) 0.4 NO_x	Δ First Cost (1974$) 2.0 NO_x	ΔMaint. Cost 50,000 mi. 1974 $
Ref. EPA Composite 1974 veh. fuel economy		0	22.3			
1. Improved Engine						
a. Dual CAT/MAIR/SEFE PEGR/Charcoal/HEI	0.41/3.4/0.4	+15.0	25.6	+277	--	-126
b. OXCAT/MAIR/SEFE/PEGR/HEI	0.41/3.4/2.0	+15.0	25.6	--	+150	similar
2. System 1 + automatic transmission w/4 speed + lock-up		+23.7	27.6	+289	+162	similar
3. System 2 + radial tires + wt. reduction + aero drag reduction + access improvement		+29.1	28.8	+337	+210	-186

*See discussion for explanation of terms.

NOTES:
1. Fuel economy is computed from EPA composite cycle.
2. Implementation of fuel economy improvements shown in this Table may be in a different order.
3. Production Volume in 1974: 2.9 million automobiles, 28%.
4. Projected 1980 production share for maximum shift to smaller cars = 40%.

TABLE 5-7 1980 LARGE SIZE VEHICLE: ENGINE TECHNOLOGY

TECHNOLOGY*	EMISSION LEVEL g/mi			FE % CHANGE	Δ 1st COST $			Δ 50,000 MILE MAINTENANCE COST-$**			LEAD TIME	COMMENT
	HC	CO	NO_x		E	S	FE	E	S	FE	(YEARS FOR %)	
1. 1974 Baseline	3.0	28	3.1	0	0	0	0	0	0	0	1	5,000 lb. inertia weight Base Case; Leaded Fuel.
2. EM/AIR/EGR/QHI/UNLEADED FUEL	1.5	15	3.1	0	+59	NA	0	-105	NA	0	0	Non-Catalyst System to Meet Standards (Unleaded Fuel).
3. OXCAT/AIR/PEGR/EFE/HEI	1.5	15	3.1	+25	+59	NA	+137	-105	NA	-81	0-10% 2-100%	Like Best '75 Cars with '75 Type System. Cost for FE Improvement Relative to System 2.
4. OXCAT/AIR EGR/QHI/HEI	.9	9.0	2.0	+5	+186	NA	0	-186	NA	0	0	Needed to Just Meet .9/9/2.0.
***5. OXCAT/MAIR/PEGR/EFE/HEI	.9	9.0	2.0	+25	+186	NA	+20	-186	NA	0	2	System Needed to Optimize at .9/9/2.0.
6. OXCAT/AIR/QHI/EGR/HEI	.41	3.4	2.0	0	+186	NA	0	-186	NA	0	2	System just to meet Emission Standards.
7. OXCAT/MAIR/SEFE/PEGR/HEI	.41	3.4	2.0	+25	+186	NA	+47	186	NA	0	2	Maintain Best '75 Economy with More Sophisticated System.
8. STRATIFIED CHARGE ENGINE (SCE)/OXCAT/PEGR	.41	3.4	2.0	+25	+186	NA	+64	186	NA	+81	5-20% 11- 100%	Lead Time is 6 Engine Lines per Year. Cost for FE Improvements is difference between SCE cost and cost of System 6 above.
9. TURBODIESEL/PEGR	.41	3.4	2.0	+37 (BTU Basis)	+186	NA	+200	-186	NA	+152	6-10% 12- 100%	Fuel Economy on Mile/BTU Basis. Cost for FE Improvements Associated with the Difference Between Diesel and System 6 above.
10. DUALCAT/AIR/QHI/EGR/HEI	.41	3.4	0.4	-15	+310	NA	0	-16	NA	0	3	More Spark Retard and Richer than '74. OXCAT and 2 Reduction CAT Changed During 50,000 Miles
11. DUALCAT/MAIR/PEGR/CHARCOAL/SEFE/HEI	.41	3.4	0.4	+25	+310	NA	+80	-16	NA	-170	3	Advanced Technology not yet Completely Demonstrated, Charcoal Changed Once. No CAT change.
12. SCE/OXCAT/PEGR/CHARCOAL	.41	3.4	0.4	+25	+310	NA	-60	16	NA	-69	5-20% 11- 100%	Lead Time is 6 Lines per Year. Cost for FE Improvements is difference between SCE cost and cost of System 10 above

*Technology abbreviations explained in Glossary in Appendix 5.
**Negative cost figures represent a savings over 1974 baseline vehicles.
***Systems 5-12 not demonstrated in production.

Code: E = EMISSIONS; S = SAFETY; FE = FUEL ECONOMY; EM = ENGINE MODIFICATIONS

Table 5-8 provides similar information for the non-engine related technologies considered.

For each engine system the change in fuel economy compared to 1974 is given as a percentage value. Note that more than one system is shown for all post-1974 emission standards. For any given emission standard there is a variety of different engine systems capable of achieving compliance. The system choice, therefore, depends on considerations other than emissions capability. Some of these other considerations, quantified in Table 5-7 as differences relative to the 1974 baseline, are fuel economy, first cost and maintenance cost. Lead time required for development of each system is also indicated.

For each emission level considered, the first or "prime" system shown is the one considered by industry in most public news releases. Lowest first cost systems seem historically to have been the ones most utilized when cost/fuel economy/driveability trade-offs were made. It can be seen from the summary Table 5-7 that the "prime" systems have the lowest first cost for a given emission level and they result in the lowest fuel economy compared to 1974.

The second system listed for each emission level is a system which allows optimization of fuel econmy when using conventional engine technology. The basic philosophy of trading off system cost vs. fuel economy was assumed. In every case the second system yields improved economy at higher first cost.

The first cost of each system is divided into three areas.

1. that portion related to meeting the emission standards:
2. that portion related to meeting safety standards;
3. that portion related to fuel economy optimization.

None of the engine systems has a significant safety-related cost, so that column is marked "NA" for each of the thirteen systems considered.

TABLE 5-8 1980 LARGE SIZE VEHICLE: "OTHER" VEHICLE TECHNOLOGY

TECHNOLOGY	IMPACT CONSIDERATIONS	FE % CHANGE	1st COST (in 1974 $)			Δ 50,000 MILE MAINTENANCE COST $*			LEAD TIME	COMMENT
			E	S	FE	E	S	FE	(YEARS FOR %)	
13. TRANSMISSIONS: (a) 4 SPEED W. LOCK-UP IN HIGH GEAR		+8.7	NA	NA	+16	NA	NA	0	6-50%	Industry comments indicate progress already underway. Complete phase-in prior to 1980.
(b) CONTINUOUSLY VARIABLE	Unknown Effect	+20	NA	NA	+125	NA	NA	0	8-10%	CVT might be possible by 1985. (Little enthusiasm).
14. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN.	Beneficial effect at all emission levels, post-1977 damageability +30 mph barrier	+8	NA	+200	[illegible]	NA	NA	0	5	Combination of materials substitution and body redesign for a [illegible] lb. reduction in weight with a [illegible] lb. safety related weight increase ([illegible] lbs., +[illegible] lbs.).
15. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN.	Post-1977 damageability +40 mph barrier	+12	NA	+300	500	NA	0	0	15-100%	Improved body design, plus safety requirement of [illegible] mph crash worthiness (-1,000 lbs., +[illegible] lbs.).
16. WEIGHT REDUCTION, MATERIAL SUBSTITUTION, PLUS BODY REDESIGN	Post-1977 damageability +50 mph barrier	[illegible]	NA	+350	800	NA	0	0	20-100%	Improved body devices, and safety weight increases (-1000 lbs., +[illegible] lbs.).
17. AERODYNAMIC DRAG REDUCTION 10%	Beneficial	+1.5	NA	NA	NA	NA	NA	NA	6-50%	Industry indicated that aero-drag reductions are now underway.
18. ACCESSORIES	--	+1.4	NA	NA	+10	NA	NA	NA	2-50%	Improvement in air conditioner drive control.
19. ROLLING RESISTANCE REDUCTION	--	+2.5	NA	NA	+100	NA	NA	-100	1-100%	Radial tires assumed. Will be 91% of market in 1975. Complete conversions for new models shortly thereafter. Initial cost assumption based on large volume sales.
20. REDUCED ACCELERATION PERFORMANCE	Uncertain Impact	+15	NA	NA	-40	NA	NA	NA	2-100%	0-60 acceleration increases from 12 to 18 seconds. Makes Large vehicle perform like the Average Small vehicle. (Less benefit for mid size vehicle, no benefit for small vehicle.)

*Negative cost figures represent a savings over 1974 baseline vehicles.

Codes: E = EMISSIONS, S = SAFETY, FE = FUEL ECONOMY, EM = ENGINE MODIFICATIONS

For most cases, the "prime" system has a lower first cost than the second system listed and the cost is considered entirely related to meeting the emission standards. The emissions-related first cost of the "prime" systems is assigned to all other systems designed to meet the same emission level. In short, the portion of total system cost related to just achieving the emission standards is equal to the cost of the lowest price system that would do the job. The difference in first cost between the amount required to just meet the standards and the total first cost of a system appears in the fuel economy related column (FE) of the first cost portion of the table.

The change in maintenance costs compared to 1974 systems over 50,000 miles of service is also tabulated, although the service life of cars is typically 100,000 miles. The conventional engine systems all show a substantial savings in maintenance cost due primarily to the use of unleaded fuel which prolongs exhaust system life, spark plug life, and oil change intervals.[16] Additional benefit is obtained with catalyst systems that use high energy ignition because spark plug life is further extended and fewer tune-ups are required. When catalyst changes are required, as with System #10, the cost of the catalyst change reduces the benefit of the unleaded fuel usage considerably. Note that System #11 (a system designed to optimize fuel economy), also reduces maintenance cost because it obviates the need for catalyst replacement. The reduction in maintenance cost due to the elimination of catalyst replacement appears in the "FE" column of the table because it was related to the use of a system for fuel economy optimization. As a final comment, less data is available to support the maintenance cost estimates contained herein.

The lead time column of the table gives the time from the fall of 1974 required for the system to be produced on 100% of production unless otherwise specified. Included in the lead time estimate is an allowance of any research and development work expected to be necessary before production designs can be formulated and tooling orders placed.

6. INDIVIDUAL MANUFACTURERS REVIEWS

This section contains reviews of twelve specific automotive manufacturers. These manufacturers were chosen because they represent the top selling manufacturers in the U.S., and because they currently market a wide range of vehicle types.

The discussion of each manufacturer contains a brief discussion of what his place in the market is, how his fuel economy currently compares to the market as a whole, and what types of vehicles he sells. It also contains a description of what specific individual improvements are likely to be introduced by that manufacturer in an attempt to improve fuel economy, and what improvements are precluded for him.

6.1 GENERAL MOTORS (GM)

GM is the largest manufacturer in the U.S. market, having had approximately 45% of all of the sales in the U.S. for the past several years, although their 1974 share of the market is a bit lower than it historically has been. GM's sales are concentrated heavily in the Large and Mid-size classes for 1974, with only the Chevrolet Vega and the Opel in the Small class. GM's overall sales weighted fuel economy for 1974 of 12.2 mpg is the lowest of all the 12 manufacturers considered, more than 12% less than the sales weighted industry average.

6.1.1 Power Requirement Reduction

The panel estimates for GM were based on the nominal weight reduction values of 10, 10, and zero percent for the large, mid-size and small vehicles, respectively, yielding fuel economy improvements of 8, 7 and zero percent for the three classes. This is achievable on 100% of GM's production by 1980, as are the nominal aerodynamic improvements. The improvements for radial tires were adjusted to reflect the current (1974) use of radials on GM cars.

6.1.2 Driveline Improvements

GM can achieve the nominal improvements in the driveline area by 1980, since an active program is underway.

6.1.3 Engine Improvements

GM's engine improvements are somewhat larger than the nominal due to their lower than average 1974 performance. The composite engine improvement of +30% has almost been achieved in their 1975 models.

The small improvement for stratified charge engines for GM for 1980 is based on the estimate that only 20% of GM's production could be stratified charge by 1980, and that GM would use the prechamber stratified charge engine, since GM is concentrating R&D on this engine type, not the open chamber engine.

The panel estimated no gains in fuel economy for GM by 1980 due to the use of Diesel engines, because the estimate for the earliest significant production of Diesels by GM was post-1980, due to the lack of effort in this area currently at GM.

6.1.4 Composite Improvements

The composite improvements by 1980 of +42% are based on the use of the conventional engine.

6.2 FORD

Ford is the second largest selling manufacturer in the U.S. market, typically capturing somewhat over 25% of the total U.S. sales. Ford's 1974 market share appears to have remained equal to what they have sold recently. Ford is a balanced manufacturer, selling a relatively high percentage of their sales in all three classes. Ford's overall sales weighted fuel economy for 1974 is approximately 4% above the sales weighted industry average, placing Ford 9th out of the 12 manufacturers considered.

TABLE 6-1 SUMMARY CHART: GM

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction	8	7	0
	2. rolling resistance reduction	1.6	2	2.3
	3. aero drag reduction	1.5	1.5	1.5
DRIVELINE	4. extra gear or overdrive and 5. high gear lock-up	8.7	8.7	6.4
ENGINE	6. conventional engine	29.6	21.5	14
	7. stratified charge, 2.0 NO_x	2	2	0
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency	1.4	1.4	1.4

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6,11	1974 Baseline		10.1	31		12.4	56		22	13		12.2
	1980 with 1974 sales distribution	50.8	15.2	31	42.1	17.6		25.6	27.6		43	17.5

6.2.1 Power Requirement Reduction

The weight reductions possible by Ford are the nominal values for the three classes of vehicles. These improvements, along with the nominal aerodynamic improvements, are possible on 100 percent of Ford's production by 1980. The improvement values for radial tires were adjusted to reflect Ford's current 1974 use of radials which is extensive.

6.2.2 Driveline Improvements

Ford, like GM, is currently investigating transmission and driveline improvements extensively. The panel estimates that the improvements that are possible for GM in this area are also possible for Ford.

6.2.3 Engine Improvements

Ford's lesser improvement, compared to GM, for conventional engines reflects the fact that Ford was somewhat ahead of GM in 1974, and therefore can only improve a lesser amount, plus the fact that Ford sells a more balanced model mix.

The improvements for Ford in the stratified charge engine area are based on use of the PROCO engine, an engine on which the panel assumes that Ford has leadership in the development area. The percent of Ford production that could be PROCO-equipped in 1980 is 40 percent.

The panel estimates that Ford like GM could not have any Diesel engines in production by 1980 due to lack of effort in this area currently.

6.2.4 Composite Improvements

The composite improvement for Ford of +35.4% is based on the use of the conventional engine in 1980.

TABLE 6-2 SUMMARY CHART: FORD

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction	8	7	0
	2. rolling resistance reduction	.8	1.8	1.8
	3. aero drag reduction	1.5	1.5	1.5
DRIVELINE	4. extra gear or overdrive and 5. high gear lock-up	8.7	8.7	6.4
ENGINE	6. conventional engine	21.2	18.5	13.1
	7. stratified charge, 2.0 NO_x	8.5	7.4	5.2
	8. stratified charge, 0.4 NO_x	8.5	7.4	5.2
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency	1.4	1.4	1.4

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6,11	1974 Baseline		10.7	30		14.3	38		21.9	32		14.4
	1980 with 1974 sales distribution	41.6	15.1		38.7	19.8		24.2	27.2		36.1	19.6

6.3 CHRYSLER

Chrysler is the third largest selling manufacturer in the U.S. market, typically capturing 13 to 15% of all U.S. sales. Chrysler's share of the U.S. market appears to have increased slightly for 1974. Chrysler sells in all three classes, but Chrysler does not make small cars domestically. The small car they market (the Dodge Colt) is made for them in Japan by Mitsubishi. Most of Chrysler's sales are in the mid-size class. Chrysler's overall sales weighted fuel economy for 1974 was about 1% more than the sales weighted industry average, placing Chrysler 10th among the 12 manufacturers considered.

6.3.1 Power Requirement Reduction

Chrysler, because of their currently more weight efficient body construction cannot improve the full 10 percent. Chrysler can improve in weight reduction but only by 7 percent. This will require Chrysler to have possibly more materials substitution than GM or Ford. Chrysler has the capability to reduce by 7 percent on 100% of production by 1980.

6.3.2 Driveline Improvements

Chrysler has the capability to incorporate the improved transmissions on 100% of their production in 1980.

6.3.3 Engine Improvements

Because of their good performance currently (1974) Chrysler can improve by a lesser amount than the average in the conventional engine area.

Chrysler is not shown to have any production capability for stratified charge engines by 1980 even though they have what appears to be sort of half-hearted development program with Texaco on the TCCS engine.

Chrysler has the capability to market Diesel engines in 10 percent of their sales by 1980, despite lack of effort in this area currently. This is because Chrysler now imports and sells the

TABLE 6-3 SUMMARY CHART: CHRYSLER

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction	5.6	4.9	0
	2. rolling resistance reduction	2.1	2.4	2.5
	3. aero drag reduction	1.5	1.5	1.5
DRIVELINE	4. extra gear or overdrive and 5. high gear lock-up	8.7	8.7	6.4
ENGINE	6. conventional engine	21.6	12.8	4.8
	7. stratified charge, 2.0 NO_x			
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency	1.4	1.4	1.4

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6,11	1974 Baseline		11.4	40		16	56		26.3	4		14.0
	1980 with 1974 sales distribution	40.9	16.0		31.7	21		16.6	30.7		34.3	18.8

Nissan Diesel engine in the U.S. which could be integrated into the mid-size Chrysler automobiles for taxicab use, for example. The Diesel is not shown to meet the 0.4 NOx level for Chrysler, since the current Nissan engine doesn't and Chrysler is apparently not working to improve its emissions.

6.3.4 Composite Improvements

Chrysler's composite improvements of +33.4% is based on the use of conventional engines.

6.4 AMERICAN MOTORS (AMC)

AMC has recently been competing with Volkswagen and Toyota for 4th place in the U.S. market on a total sales basis, capturing about 3 to 5% of the U.S. market. AMC's percent of the market increased slightly for 1974. AMC sells primarily in the mid-size and small classes with almost no sales in the large class, on a percentage basis. AMC's sales weighted fuel economy for 1974 was more than 19% higher than the sales weighted industry average, placing AMC 8th out of the 12 manufacturers considered.

6.4.1 Power Requirement Reduction

Because AMC sells mid-size and small cars almost exclusively, they cannot get the maximum weight reduction on a sales weighted basis, especially considering that AMC uses unitized construction. Relying on materials substitution, like Chrysler AMC could get a 7 percent weight reduction on its mid-size cars by 1980.

6.4.2 Driveline Improvements

Since AMC buys its transmissions from suppliers who will be building improved automatic transmissions they will be able to get the same improvement.

6.4.3 Engine Improvements

The engine improvements for AMC are concentrated in the small and mid-size class. Their room for improvement in the small class is greater than the average.

TABLE 6-4 SUMMARY CHART: AMC

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction		4.9	0
	2. rolling resistance reduction		2.3	2.4
	3. aero drag reduction		1.5	1.5
DRIVELINE	4. extra gear or overdrive and 5. high gear lock-up		8.7	6.4
ENGINE	6. conventional engine		28.8	24.2
	7. stratified charge, 2.0 NO_x			
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline					14.4	46		19.2	54		16.6
	1980 with 1974 sales distribution				46.2	21.1		33.6	25.7		41.	23.4

Production by AMC of alternate engines was considered to be not feasible by the panel by 1980.

6.4.4 Composite Improvements

AMC's composite improvement of +41% is based on use of the conventional engine.

6.5 VOLKSWAGEN (VW)

VW has recently been the 4th largest selling manufacturer in U.S. sales, capturing about 4 to 5% of the market. VW is exclusively a small car manufacturer currently. VW's overall sales weighted fuel economy for 1974 was more than 85% higher than the sales weighted industry average placing VW 2nd out of the 12 manufacturers considered.

6.5.1 Power Requirement Reduction

VW is a small car manufacturer. Therefore their power requirement reduction is based on no weight reduction just the radial tire and drag coefficient improvement.

6.5.2 Driveline Improvements

The nominal drivetrain improvements are possible for VW on 100% of production by 1980.

6.5.3 Engine Improvements

VW's engine improvement of 11 percent is lower than the nominal 15 percent average due to the current VW performance in the small car class, and the fact that current VW's have low power to weight ratios.

6.5.4 Composite Improvements

VW's composite improvement of +21.4% is based on use of the conventional engine.

TABLE 6-5 SUMMARY CHART: VW

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction 2. rolling resistance reduction 3. aero drag reduction			0 1.8 1.5
DRIVELINE	4. extra gear or overdrive 5. high gear lock-up			6.4
ENGINE	6. conventional engine 7. stratified charge, 2.0 NO_x 8. stratified charge, 0.4 NO_x 9. turbo diesel, 2.0 NO_x 10. turbo diesel, 0.4 NO_x			11.7
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline								25.8			25.8
	1980 with 1974 sales distribution							21.4	3.3		21.4	31.3

6.6 TOYOTA

Toyota has recently been about 6th in total U.S. sales capturing around 3 percent of the U.S. market. For 1974 Toyota has increased their market penetration and was ahead of VW at one time in sales during the year. Toyota sells in both the Small and mid-size classes with the bulk of their sales concentrated in the small class. Toyota's overall sales weighted fuel economy for 1974 was nearly 60 percent higher than the sales weighted industry average, placing Toyota 5th out of the 12 manufacturers considered.

6.6.1 Power Requirement Reduction

Toyota gets no weight reduction for their mid-size car since it is already a weight-efficient design. The only improvements are radials and drag reduction.

6.6.2 Driveline Improvements

Toyota does not get the full 8.7 percent for transmission improvements on their mid-size cars due to the large percentage of standard transmission expected to be used in 1980 in this type vehicle.

6.6.3 Engine Improvements

Toyota's improvements in the engine area are somewhat greater than the nominal, reflecting their current 1974 position.

6.6.4 Composite Improvements

Toyota's composite improvement of +33.3% is based on use of the conventional engine.

6.7 NISSAN

Nissan has recently been about 7th in U.S. sales capturing about 2 percent of the U.S. market, with slight increases expected for 1974. Nissan sells vehicles in the small class only. Nissan's

TABLE 6-6 SUMMARY CHART: TOYOTA

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction		0	0
	2. rolling resistance reduction		1.3	1.3
	3. aero drag reduction		1.5	1.5
DRIVELINE	4. extra gear or overdrive 5. high gear lock-up		6.4	6.4
ENGINE	6. conventional engine		23.5	23.9
	7. stratified charge, 2.0 NO_x			
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline					19.3	12		22.7	88		22.2
	1980 with 1974 sales distribution				32.7	25.6		33.1	30.3		33.3	29.6

1974 overall sales-weight fuel economy was more than 70% higher than the sales-weighted industry average, placing Nissan 3rd out of the 12 manufacturers considered.

6.7.1 Power Requirement Reduction

Nissan, like other small car manufacturers gets only the radial tire and drag improvements.

6.7.2 Driveline Improvements

Nissan can produce the improved transmission on 100% of production by 1980.

6.7.3 Engine Improvements

Nissan's improvement of +11% reflects their current good performance, compared to the average.

Nissan is the only manufacturer who could introduce a car significantly larger than they now market in 1980. This would be the Nissan Diesel, a Mid-size car which gets the same fuel economy as the small cars Nissan now sells.

6.7.4 Composite Improvements

Nissan's composite improvement of 21.6% is based on the use of the conventional engine. If Nissan introduces the mid-size Nissan 220 Cedric Diesel their sales-weighted fuel economy improvement would be the same.

6.8 VOLVO

Volvo has historically been a rather small percent of the U.S. market, capturing less than 1 percent of the total U.S. sales. Volvo sells mid-size cars only. Volvo's overall sales-weighted fuel economy for 1974 was over 35 percent higher than the sales weighted industry average, placing Volvo 7th out of the 12 manufacturers.

TABLE 6-7 SUMMARY CHART: NISSAN

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction 2. rolling resistance reduction 3. aero drag reduction			0 1.9 1.5
DRIVELINE	4. extra gear or overdrive 5. high gear lock-up			6.4
ENGINE	6. conventional engine 7. stratified charge, 2.0 NO_x 8. stratified charge, 0.4 NO_x 9. turbo diesel, 2.0 NO_x 10. turbo diesel, 0.4 NO_x			11.8
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline								24.1	100		24.1
	1980 with 1974 sales distribution							21.6	29.3		21.6	29.3
	1980 with Diesel				NA	29.3	10	21.6	29.3	90	21.6	29.3

6.8.1 Power Requirement Reduction

Since Volvo already has a weight-efficient mid-size car with radial tires they can only improve by use of improved drag coefficient.

6.8.2 Driveline Improvements

Many Volvos are standard transmissions this trend is expected by the panel to continue in 1980.

6.8.3 Engine Improvements

Volvo's engine improvements are about the average for the mid-size class.

6.8.4 Composite Improvements

Volvo's composite improvement of +27.2% is based on use of the conventional engine.

6.9 FIAT

Fiat is another small part of the U.S. market, typically with less than 1 percent of the total U.S. sales. Fiat sells in the small class only, and their 1974 sales weighted fuel economy was more than 55 percent higher than the sales-weighted industry average placing Fiat 6th out of the 12 manufacturers considered.

6.9.1 Power Requirement Reduction

Fiat's improvements in this area are solely aerodynamic drag reductions.

6.9.2 Driveline Improvements

Fiat has the capability to introduce improved transmissions across the board by 1980.

6.9.3 Engine Improvements

Fiat can achieve a large improvement in this area, due to their current lower than average improvement.

TABLE 6-8 SUMMARY CHART: VOLVO

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction 2. rolling resistance reduction 3. aero drag reduction		0 0 1.5	
DRIVELINE	4. extra gear or overdrive 5. high gear lock-up		6.4	
ENGINE	6. conventional engine 7. stratified charge, 2.0 NO_x 8. stratified charge, 0.4 NO_x 9. turbo diesel, 2.0 NO_x 10. turbo diesel, 0.4 NO_x		19.3	
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline					19.3						19.3
	1980 with 1974 sales distribution				27.2	24.5					27.2	24.5

TABLE 6-9 SUMMARY CHART: FIAT

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction			0
	2. rolling resistance reduction			0
	3. aero drag reduction			1.5
DRIVELINE	4. extra gear or overdrive			6.4
	5. high gear lock-up			
ENGINE	6. conventional engine			28.3
	7. stratified charge, 2.0 NO_x			
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline								22.0			22.0
	1980 with 1974 sales distribution							36.2	30.0		36.2	30.0

6.9.4 Composite Improvements

Fiat's composite improvement of 36.2% is dominated by engine improvements.

6.10 HONDA

Honda is the smaller in sales of all 12 manufacturers considered in this report. Honda sells vehicles in the small class only and Honda's sales weighted fuel economy for 1974 was more than 110% higher than the sales weighted industry average, Honda ranked first in fuel economy of all the 12 manufacturers considered.

6.10.1 Power Requirement Reduction

Honda loses fuel economy due to weight increases - resulting in Honda increasing in weight by 10 percent and moving into the 2250 IW class.

6.10.2 Driveline Improvements

Since Honda's current automatic transmission is not the best, they can improve more in this area than other manufacturers.

6.10.3 Engine Improvements

Honda's small improvement reflects their current good performance, and the use of the CVCC stratified charge engine.

Honda is one of the few manufacturers to have the demonstrated capability to meet 0.4 NOx, albeit with a fuel economy loss.

6.10.4 Composite Improvements

The composite fuel economy improvement for Honda of +6.2% is based on the use of the CVCC engine at 2.0 NOx, at 0.4 NOx Honda loses 13.8% in fuel economy. It is interesting to note that even the 13.8% loss makes Honda 87% better than the 1974 industry average, but a 20% improvement standard along with 0.4 NOx would wipe them out of the market.

TABLE 6-10 SUMMARY CHART: HONDA

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction			-8
	2. rolling resistance reduction			1.8
	3. aero drag reduction			1.5
DRIVELINE	4. extra gear or overdrive			9.0
	5. high gear lock-up			
ENGINE	6. conventional engine			-
	7. stratified charge, 2.0 NO_x			1.9
	8. stratified charge, 0.4 NO_x			-18
	9. turbo diesel, 2.0 NO_x			-
	10. turbo diesel, 0.4 NO_x			-
ACCESSORY	11. accessory efficiency			-

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
	1974 Baseline								30.3	100		30.3
1 - 5, 7	1980 with 1974 sales distribution							6.2	32.2		6.2	32.2
1 - 5, 8	1980/0.4 g/mi NOx							-13.8	26.1		-13.8	26.1

6.11 TOYO KOGYO (T-K)

T-K has captured about 1 percent of the U.S. market recently. T-K sells vehicles in the small and mid-size classes, about equally divided. T-K's sales weighted fuel economy for 1974 was about 2 percent lower than the sales weighted industry average placing T-K 11th out of the 12 manufacturers.

6.11.1 Power Requirement Reduction

Since Toyo Kogyo already produces a weight efficient mid-size car, and has a high current radial tire installation rate their improvements in this area are limited to aerodynamic drag improvements.

6.11.2 Driveline Improvements

Toyo Kogyo has the transmission technology to achieve the nominal improvements by 1980.

6.11.3 Engine Improvements

Toyo Kogyo's engine improvements are larger than for any other manufacturer. The panel estimates that Toyo Kogyo can make the predicted improvements, due to their extremely strong technical capability and the recent emphasis put on fuel economy at the factory R&D level.

Although not specifically shown, Toyo Kogyo may have a stratified charge rotary engine in production by 1980.

6.11.4 Composite Improvements

Toyo Kogyo's composite improvement of 91.2% is based on use of the rotary engine in most models.

6.12 AUDI

Audi is another manufacturer with a small percent of the U.S. market, about 1% for 1974. Audi sells vehicles in both the mid-size and small classes, about equally in each. Audi's 1974

TABLE 6-11 SUMMARY CHART: TOYO KOGYO

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction		0	0
	2. rolling resistance reduction		0	0
	3. aero drag reduction		1.5	1.5
DRIVELINE	4. extra gear or overdrive		6.4	6.4
	5. high gear lock-up			
ENGINE	6. conventional engine		89.8	75.5
	7. stratified charge, 2.0 NO_x			
	8. stratified charge, 0.4 NO_x			
	9. turbo diesel, 2.0 NO_x			
	10. turbo diesel, 0.4 NO_x			
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1 - 6	1974 Baseline					12.5	52		15.0	48		13.6
	1980 with 1974 sales distribution				97.7	24.7		83.4	27.5		91.2	26.0

6.12.1 Power Requirement Reduction

Audi's only improvements are in the aerodynamic drag area.

6.12.2 Driveline Improvements

Audi will have the capability to incorporate the transmission improvements by 1980.

6.12.3 Engine Improvements

Audi's engine improvements are larger than the average for the mid-size vehicles and smaller than the average for the small size class, reflecting their current 1974 performance.

6.12.4 Composite Improvements

Audi's composite improvement of 24.2% is dominated by the engine improvements in the mid-size cars.

TABLE 6-12 SUMMARY CHART: AUDI

Individual Improvements

TYPE OF IMPROVEMENT	SPECIFIC IMPROVEMENT	PERCENT INCREASE IN FUEL ECONOMY		
		LARGE	MID - SIZE	SMALL
POWER REQUIREMENT REDUCTION	1. weight reduction 2. rolling resistance reduction 3. aero drag reduction		0 0 1.5	0 0 1.5
DRIVELINE	4. extra gear or overdrive 5. high gear lock-up		8.7	6.4
ENGINE	6. conventional engine 7. stratified charge, 2.0 NO_x 8. stratified charge, 0.4 NO_x 9. turbo diesel, 2.0 NO_x 10. turbo diesel, 0.4 NO_x		28.9	0.9
ACCESSORY	11. accessory efficiency			

Composite Improvements

SYSTEM	MODEL YEAR / MIX	LARGE			MID - SIZE			SMALL			ALL	
		% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG	% of TOTAL SALES	% FE IMPROVEMENT	MPG
1-6	1974 Baseline					18.5	48		27.4	52		22.3
	1980 with 1974 sales distribution				39.1	25.7		8.8	29.8		24.2	27.7

TABLE 6-13 SUMMARY TABLE - INDIVIDUAL MANUFACTURERS

Manufacturer	1974 Fuel Economy	1980 Fuel Economy	Percent Change
GM*	12.2	17.4	+42.6
Ford*	14.4	19.5	+35.4
Chrysler*	14.0	18.7	+33.4
AMC*	16.6	23.4	+41.0
VW	25.8	31.3	+21.4
Toyota	22.2	29.5	+33.3
Nissan	24.1	29.3	+21.6
Volvo	19.3	24.5	+27.2
Fiat	22.0	30.0	+36.2
Toyo Kogyo	13.6	26.0	+91.2
Honda	30.3	32.2	+6.2
Audi	22.3	27.7	+24.2

*Not including engine resizing or accessory improvements.

Including engine size reduction and accessory improvements the 1980 Fuel Economy is estimated to be as follows:

Ford	21.0 mpg
GM	18.9 mpg
Chrysler	20.5 mpg
AMC	24.1 mpg

7. IMPROVEMENTS IN FUEL ECONOMY FOR LIGHT DUTY TRUCKS (LDT)

Technological improvements for domestic LDT are similar to those defined in the section for passenger cars.

Applicable improvements might be:

- Aerodynamic drag reduction
- Engine improvement
- Automatic transmission improvement or addition of 4th gear
- Tires (substitution by radials)
- Air conditioning improvements
- Weight reduction

Since the primary use of these vehicles are in the local urban environment and since these vehicles require structural strength for maximum load carrying capacity, the areas that lend themselves to technological improvements are:

a. Engine improvement

b. Substitution of conventional tires by radial tires

c. Four speed transmission with lock-up in high gear or addition of additional gear in manual

As in the case of the mid-size passenger cars, an improvement of 20% in mpg due to engine improvements by 1980 is assigned. (The 20% figure rather than the 25% figure for large size cars is used because of the use of smaller displacement engines in these vehicles.) Use of radial tires will cause an additional improvement of 2.5%. Use of improved transmissions (67% automatic, 33% manual) will yield an improvement of 7.1%.

The total feasible improvement is therefore estimated to be 30% by 1980 for the domestic LDT (relative to 1974).

Imported small 1/2-ton pick-ups represent less than 10% of all LDT sales per year and less than 2% of highway vehicle sales per year. The estimated improvement for these vehicles is 20% by 1980 due to engine, transmission and tire improvements.

Incorporation of a diesel engine in the domestic LDT would make a 50% improvement by 1985 feasible (Btu basis).

The impacts for the above improvements are the same as for the passenger cars.

7.1 LIGHT DUTY TRUCK CLASSES

Conventional light duty trucks are subdivided into two categories. Category I includes vehicles of gross vehicle weight (GVW) of 6000 lbs or less, and Category II includes vehicles of 6001-10,000 lbs. GVW. Table 7-1 gives U.S. new truck registrations of these classes by manufacturer during calendar year 1973, Table 7-2 gives U.S. production by make and engine type for 1973, and Table 7-3 gives new truck registration during the first five months of calendar year 1974 for these classes of vehicles.

TABLE 7-1 U.S. NEW TRUCK REGISTRATIONS BY GVW CLASS
1973 Calendar Year
(Ward's Automotive Yearbook, 1974)

Make	6,000 Lb. or Less	6,001 - 10,000 lb.	Total Light Duty Trucks
Chevrolet	662,795	260,394	923,189
Ford	617,598	257,992	875,590
Dodge	163,115	106,125	269,240
GMC	105,265	60,003	165,268
International	71,004	30,235	101,239
Jeep	66,443	1,784	68,227
Misc.*	156,671	1	156,672
	1,842,891	716,534	2,559,425

*Miscellaneous includes imports, Divco, Hendrickson, Oskosh, Crane Carrier, etc.

TABLE 7-2 U.S. TRUCK PRODUCTION BY MAKE AND ENGINE TYPE

1973 Calendar Year
(Ward's Automotive Yearbook, 1973)

Make	6 Cyl	8 Cyl	Total Engines Gasoline
Chevrolet	96,373	909,548	1,005,921
GMC	33,901	192,109	226,010
Ford	108,377	812,496	920,873
Dodge	34,931	339,521	374,452
International	16,271	172,830	189,101
Jeep	35,545	55,387	90,932
	325,398	2,481,891	2,807,289

NOTE: Ward's Automotive Yearbook, indicates production of 3,270 4-cylinder engines by Chevrolet. These are Vega Panel Express units and are not included in the totals. Also not included are 3,097 4-cylinder engines by Jeep, since the four cylinder engine is no longer used in the Jeep utility vehicle.

TABLE 7-3 U.S. NEW TRUCK REGISTRATIONS BY GVW CLASS

1974 (5 mos) Calendar Year
(Automotive News)

Make	6000 lb. or Less	6,001 - 10,000	Total Light Duty Trucks
Chevrolet	230,491	91,990	322,481
Ford	213,123	88,964	302,087
Dodge	61,047	34,424	95,471
GMC	36,704	19,107	55,811
International	19,779	8,724	28,503
Jeep	24,293	1,106	25,399
Plymouth	187	--	187
Misc.*	44,842	4	44,846
	630,466	244,319	874,785

*Miscellaneous includes imports, Divco, Hendrickson, Oskosh, Crane Carrier, etc.

U.S. new truck registrations during the calendar year 1971 and 1972 were (Ward's Automotive Yearbook):

GVW	1971	1972
6,000 lbs or less	1,216,390	1,532,102
6001 lbs - 10,000 lbs	449,805	561,737

The principal fuel used by these trucks is gasoline and the following statistics apply (Preliminary Progress Report 8/74, Contract TSC-627, from A.D. Little, Inc. to DOT):

TABLE 7-4 LIGHT DUTY TRUCK STATISTICS

	All LDT	GVW 6000 lbs	GVW 6,001 - 10,000 lbs
Total in Service	15,368,000	11,168,000	4 200,000
Gallons of fuel consumed (millions per year)	14,152	10,100	4,052
% of highway fuel consumed	13.1	9.3	3.8
Vehicle Truck-miles per year (new Trucks)		12,000	12,000
Vehicle truck-mile/year, all-weighted average	10,600		
Primary use:			
Local urban - %	92.3		
Short range (Under 200 miles)	7.5		
Long range (Over 200 miles)	0.2		
Average Miles Per Year			
Local-Urban	10,000		
Short range	17,400		
Long range	13,000		
Average Fuel Consumption (mpg)			
Local-urban		12.2	11.7
Short range		11.0	9.8
Long Range		11.9	11.5
Weighted Average		11.7	11

The fuel economy of the domestic LDT's approximate the economy of large sized passenger cars, and since the small 1/2 ton truck imports are of approximately the same inertia weight and same engine displacement as the imported sub-compact imports these approximate the same fuel economy as the corresponding subcompacts. (Sales weighted fuel economy trends by manufacturer are not available.)

The following small light duty trucks have been imported in 1973 and 1974:

TABLE 7-5 IMPORTED 1/2-TON PICK-UP TRUCK DATA

Manufacturer	Sales	Inertia Wt. Lbs.	Sales	Inertia Wt. Lbs.
Datsun[1]	88,785	2,500	25,647	2,750
Ford Courier[2] (Toyo-Koygo)	53,303	2,750	20,285	2,750
Chevrolet Luv[3] (Isuzu)	39,422	2,750	12,485	2,750
Toyota[1]	37,466	2,750	13,157	2,750

[1] Included under miscellaneous in Tables 7-1 and 7-3.

[2] Included under Ford in Tables 7-1 and 7-3.

[3] Included under Chevrolet in Tables 7-1 and 7-3.

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16. Abstract

This Technology Panel Report is report Number Four (4) of seven (7) panel reports prepared by special panels of a task force established under joint chairmanship of the U.S. Dept. of Transportation and the U.S. Environmental Protection Agency to conduct a study of the practicability of a 20% fuel economy improvement for new motor vehicles in the 1980 time frame. Materials developed by the various study panels were used in preparing the Report to Congress entitled "Potential for Motor Vehicle Fuel Economy Improvement" dated 24 October 1974 (second printing 18 November 1974).

The authors evaluate individual technologies which could produce improved automobile fuel economy in the areas of vehicle improvement (reduced weight and aerodynamic drag), transmission improvement, engine improvements and reduced performance acceleration. Potential 1980 fuel savings are estimated for each of these technologies. The more promising of these technologies are then combined in several different configurations to produce estimates of potential automobile fuel savings possible by 1980.

The authors conclude that the domestic automobile manufacturers could increase their sales weighted automobile fuel economy by more than 30% by 1980. The manufacturers of foreign imports which are more fuel efficient than domestic automobiles could meet a 20% improvement but could not meet a 30% improvement goal by 1980.

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